NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MULTIVARIATE ANALYSIS OF THE EFFECT OF SOURCE OF SUPPLY AND CARRIER ON PROCESSING AND SHIPPING TIMES FOR ISSUE PRIORITY GROUP ONE REQUISITIONS

by

Gavan M. Sagara

June 2008

Thesis Advisor:	Samuel E. Buttrey
Second Reader:	Jonathan B. Haynes

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Multivariate Analysis of the Effect of Source of Supply and Carrier on Processing and Shipping Times for Issue Priority Group One Requisitions			**5. FUNDING NUMBERS**
6. AUTHOR(S) Gavan M. Sagara			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Priority Material Office, Bremerton, WA			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The objective of this thesis is to investigate the effects of source of supply and carrier on the delivery times of high-priority requisitions to primary destinations of Navy, Military Sealift Command, USMC ground forces, and select U.S. Coast Guard units operating in the Fifth, Sixth, and Seventh Fleet Areas of Operation (AORs), and major Fleet concentration areas within the United States. The primary focus is on determining whether source of supply, carrier, and the interaction of these two factors have an effect on processing and shipping times of high-priority requisitions. "Source of supply" refers to a Department of Defense distribution depot and "carrier" refers to a shipper, such as Federal Express®, DHL Worldwide Express®, United Parcel Service ®, Air Mobility Command and commercial freight forwarders.

This study uses Ordinary Least Squares (OLS) linear models, Generalized Linear Models (GLMs) and nonparametric methods to explore the structure of the historical requisition datasets. OLS linear models were found to be inadequate, but both the GLMs and nonparametric tests proved to be valid and yielded results from which inferences could be made. The GLM and nonparametric test results indicate that source of supply has a statistically significant effect on shipping times of high-priority requisitions, and that source of supply and carrier each have a statistically significant effect on shipping times to certain destination areas. The GLMs also indicate that there is no significant interaction between source of supply and carrier.

14. SUBJECT TERMS			**15. NUMBER OF PAGES**
High-priority requisitions, Issue Priority Group One, Source of Supply, Multivariate Regression, Generalized Linear Model, Nonparametric Analysis, Resampling, Permutation Test, and Friedman Test			155
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

MULTIVARIATE ANALYSIS OF THE EFFECT OF SOURCE OF SUPPLY AND CARRIER ON PROCESSING AND SHIPPING TIMES FOR ISSUE PRIORITY GROUP ONE REQUISITIONS

Gavan M. Sagara
Commander, United States Navy
B.S., United States Naval Academy, 1992

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2008

Author: Gavan M. Sagara

Approved by: Samuel E. Buttrey
Thesis Advisor

Jonathan B. Haynes
Second Reader

James N. Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The objective of this thesis is to investigate the effects of source of supply and carrier on the delivery times of high-priority requisitions to primary destinations of Navy, Military Sealift Command, USMC ground forces, and select U.S. Coast Guard units operating in the Fifth, Sixth, and Seventh Fleet Areas of Operation (AORs), and major Fleet concentration areas within the United States. The primary focus is on determining whether source of supply, carrier, and the interaction of these two factors have an effect on processing and shipping times of high-priority requisitions. “Source of supply” refers to a Department of Defense distribution depot and “carrier” refers to a shipper, such as Federal Express®, DHL Worldwide Express®, United Parcel Service, Inc.®, Air Mobility Command and commercial freight forwarders.

This study uses Ordinary Least Squares (OLS) linear models, Generalized Linear Models (GLMs) and nonparametric methods to explore the structure of the historical requisition datasets. OLS linear models were found to be inadequate, but both the GLMs and nonparametric tests proved to be valid and yielded results from which inferences could be made. The GLM and nonparametric test results indicate that source of supply has a statistically significant effect on processing times of high-priority requisitions, and that source of supply and carrier each have a statistically significant effect on shipping times to certain destination areas. The GLMs also indicate that there is no significant interaction between source of supply and carrier.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

EXECUTIVE SUMMARY

The Department of Defense (DoD) and the U.S. Navy are continuously seeking opportunities to improve the efficiency of logistic operations. Customer Wait Time (CWT) is defined as the total elapsed time between issuance of a customer order and satisfaction of that order. Two key components of CWT that the Navy desires to reduce are processing time and shipping time. Although reducing the CWT for all categories and priorities of requisitions is desired, reducing the CWT for the highest priority requisitions, often referred to as Issue Priority Group One (IPG-1) requisitions, is most important. The focus of this thesis is on IPG-1 requisitions submitted to the Priority Material Office (PMO) located in Bremerton WA, which is the point-of-entry for IPG-1 requisitions from the entire submarine force, the entire surface force, Military Sealift Command, deployed USMC ground forces, various Naval Expeditionary Forces, various Naval Special Warfare units, select U.S. Coast Guard units, and various Navy ashore maintenance activities.

This study examines the impact of source of supply and carrier on processing times and shipping times of the highest priority requisitions to the primary overseas destinations of U.S. Navy units operating in the Fifth, Sixth, and Seventh Fleet Areas of Operation (AORs) and major Fleet concentration areas within the United States. There has been a similar study for Air Force requisitions, as well as a study for Navy high-priority requisitions conducted in 2003 that was comparatively limited in scope due to existing command areas of responsibility (only Navy submarine and surface force customers assigned to the Pacific Fleet), and supply source and carriers in use during that time frame.

The data used in this study were taken from the Priority Material Office's requisition database for the period February 2005 to February 2008. This study included eleven primary overseas destinations (Atsugi, Bahrain, Guam, Hong Kong, Mildenhall (UK), Okinawa, Rota, Sasebo, Sigonella, Singapore, and Yokosuka) and eight primary CONUS destinations (Bangor/Bremerton, Everett, Groton, Kings Bay, Mayport, Norfolk, Pearl Harbor, and San Diego).

This thesis is limited to primary sources of supply for IPG-1 requisitions. For this study, a primary source of supply is defined as a single DoD or Navy supply center, or a group of DoD and Navy supply activities within a single geographic location (e.g. Fleet and Industrial Supply Center, San Diego, and Defense Distribution Center, San Diego) that shipped at least 200 IPG-1 requisitions during the three-year period of the historical requisition data, or was of particular interest to PMO. Federal Express® (FedEx®), DHL Worldwide Express® (DHL®), United Parcel Service, Inc.® (UPS®), Air Mobility Command (AMC) and commercial freight forwarders are the carriers included in the analysis. Customers include Pacific and Atlantic Fleet units, as well as deployed Marine ground forces.

Ordinary Least Squares (OLS) models were deemed inadequate to analyze the historical requisition data. However, Poisson Generalized Linear Models (GLMs) provided valid models from which results could be gleaned. GLMs were utilized to explain and explore the effect of source of supply on processing times, and source of supply and carrier on shipping times. Additionally, GLMs showed that there was no significant interaction between the two variables.

Nonparametric permutation and Friedman test results supported the GLM results by showing that source of supply has a statistically significant effect on high-priority requisition processing times, and that source of supply and carrier each have a statistically significant effect on shipping times to certain destination locations. Specifically, selecting Defense Distribution Depot Albany, GA (DDAG), Defense Distribution Depot Pearl Harbor, HI (DDPH), or Defense Distribution Depot Susquehanna, PA (DDSP) as a source of supply has a statistically significant effect on processing time at a 0.002 level of significance, and selecting USS EMORY S LAND has a statistically significant effect at a level of 0.01. Also, at significance levels of 0.04 and 0.05, source of supply selection has a statistically significant effect on requisitions shipped to the Okinawa and Pearl Harbor destination areas. Carrier selection has a statistically significant effect on requisitions shipped to Groton, Guam, Norfolk, Pearl Harbor, and Singapore at significance levels of 0.048, 0.002, 0.002, 0.016, and 0.002, respectively.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my wife, Ronda, for her love, patience and understanding during this writing and over the past two years of study. Without her support, this project would not have been possible and our two boys would have starved. Thank you, Ronda, for everything that you do for me, and for our family. Bravo Zulu!

I would like to express my thanks to my thesis advisor, Dr. Samuel Buttrey, for his continued support and guidance during this research. With your guidance and mentoring, I gained another level of appreciation for the effects that statistical analysis can provide to our tactical operators at the receiving end of the supply chain.

I would also like to thank CDR Jonathan Haynes, Commanding Officer, Priority Material Office, NPS OR alumni, and former college roommate. The insight, data and support he provided were invaluable. I sincerely appreciate the opportunity to support your mission and organization, and the chance to work with you on a project that will hopefully be of use to the Fleet.

Lastly, I would like to thank my grand-uncle Robert K. Sagara for his service to our country during World War II, and for inspiring me to military service. You will never be forgotten.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) and the U.S. Navy are continuously seeking opportunities to improve the efficiency of logistic operations. The *FY2000 Department of Defense Logistics Strategic Plan* calls for significant reductions in the Customer Wait Time (CWT) (FY2000 Department of Defense Logistics Strategic Plan, 1999, p. 15). As one of the main focus areas for logistics planning and executing improvements, CWT has been established in the past few years as the key DoD logistics performance metric (FY2000 Department of Defense Logistics Strategic Plan, 1999, p. 14). CWT is the total elapsed time between issuance of a customer order and satisfaction of that order and ideally includes all customer orders, regardless of commodity or source, immediate issues as well as backorders. It includes issues from wholesale and retail stocks as well as various other arrangements (FY2000 Department of Defense Logistics Strategic Plan, 1999, p. 20). One of the main goals stated in the *Defense Logistics Agency Strategic Plan: FY07 – FY13* is the improvement of internal DLA processes to continuously improve performance through better processes and business arrangements to improve quality and speed of supply chain management (Defense Logistics Agency Strategic Plan: FY07 – FY13, 2007, p. 6). In the last several years, the Navy has sought to reduce the overall CWT by addressing each CWT component. Two key components of CWT that the Navy desires to reduce are processing time and shipping time. Processing time is the time between receipt of requisition at a DoD source of supply and the time of carrier pick-up at the DoD source of supply. Shipping time is the time between carrier pick-up at a DoD source of supply and the time of delivery at the requisitioner's destination.

Although reducing the processing and shipping times for all requisition categories and priorities is desired, reducing the processing and shipping times for the highest priority requisitions, often referred to as Issue Priority Group One (IPG-1) requisitions, receives the most attention. Previously, the Navy had two primary commands that served as the point-of-entry for IPG-1 requisitions: the Priority Material Office (PMO) in

Bremerton, WA and the Atlantic Fleet Logistic Support Center (AFLSC) in Norfolk, VA. AFLSC was merged into PMO in 2004, effectively making PMO the sole point-of-entry for Navy IPG-1 requisitions. The focus of this thesis is on Navy IPG-1 requisitions, all of which are handled by PMO.

PMO is the point-of-entry and expediter for IPG-1 requisitions from Pacific and Atlantic Fleet units, excluding aircraft carriers. When PMO receives an IPG-1 requisition, it queries the DoD supply system to determine which DoD distribution depot or center can satisfy the requirement. When the part is located, a PMO expeditor forwards the requisition to the distribution depot carrying the part and directs the distribution depot to ship the part. PMO provides the destination to which the part is to be shipped and the desired mode of transportation, which is a commercial air carrier, Air Mobility Command (AMC), or a commercial freight forwarder.

PMO does not currently utilize statistical analysis of historical shipping data to determine the optimal combination of supply source and carrier that has historically resulted in the shortest mean processing and shipping times. In practice, if a part is available at more than one DoD distribution depot, the individual at PMO responsible for expediting the requisition makes his or her decision based on personal experience and/or corporate knowledge to determine which distribution depot will issue the part, and the Defense Logistics Agency (DLA) decides which carrier will be used to deliver the part.

The hypothetical scenario presented below is based on PMO's Commanding Officer's perceptions that his expediters may be selecting sources of supply and shipping carriers using anecdotal information rather than quantitative data to support their choices:

> USS MICHIGAN (SSGN 727), which recently sailed from Bangor, WA for a six-month deployment to the Persian Gulf, has a power supply fail on its sonar system. A spare power supply is not available on board, so an IPG-1 requisition is submitted by the ship to PMO via a secure e-mail. The ship will conduct a small boat personnel (BSP) transfer off Oahu in two days and requests PMO have the part shipped to Naval Submarine Support Command (NSSC) Pearl Harbor, which will then deliver the part during the BSP. PMO's duty expediter screens the supply system for stock availability and determines that assets are available at three different Defense Distribution Depots (DD): DD Puget Sound in Washington, DD San Joaquin in California, and DD Norfolk in Virginia. The expediter

> requests to have the item shipped via Federal Express® from DD Puget Sound. The required part arrives on Oahu in two days, but after the BSP occurs.

The above scenario illustrates the possible advantages of having established procedures based on quantitative analysis of supply source and carrier combinations that have historically resulted in shortest processing and shipping times to the IPG-1 requisitioner's destination. The Commanding Officer of PMO is interested in establishing a formal protocol in selecting source of supply and carrier, rather than simply using individual experience and corporate knowledge, for expediters to utilize when expediting IPG-1 requisitions to destinations around the world (Conversation between Commander Jonathan Haynes, Priority Material Office and the author, 21 February 2008).

B. OBJECTIVES

The purpose of this thesis research is to analyze the effect of source of supply and carrier on processing and shipping times for IPG-1 requisitions. In the course of the study, the following questions are answered:

- Is there statistical evidence to indicate that source of supply affects processing times of IPG-1 requisitions to destinations within the Fifth, Sixth, and Seventh Fleet AORs and continental U.S.?
- Is there statistical evidence to indicate that source of supply, carrier, and/or the interaction of these two variables, affect shipping times of IPG-1 requisitions to destinations within the Fifth, Sixth, and Seventh Fleet AORs and continental U.S.?
- What carrier, source of supply, and combinations of these two factors have the smallest mean processing and shipping times for the various destinations?

To assist with the analysis, PMO provided three years of IPG-1 requisition data, dating from February 2005 to February 2008. This data included requisition numbers, sources of shipment, material issue processing times, destinations of shipment, shipping times from source to destination, and carriers.

C. SCOPE, LIMITATIONS AND ASSUMPTIONS

The analyzed data was limited to IPG-1 requisitions that were submitted to PMO and filled from DoD supply system stocks, or acquired via commercial contract. It does not include requisitions satisfied through open purchase from commercial sources or through cannibalization from other naval operating units. Additionally, only IPG-1 requisitions shipped via primary air carriers, AMC and commercial freight forwarders from major DoD supply centers to major overseas and continental U.S. (CONUS) destinations of Pacific and Atlantic Fleet units were included in this study. Primary air carriers and commercial freight forwarders, major DoD supply centers, and major overseas and CONUS supply destinations are defined in Chapter III. The data analyzed covers the time period of February 2005 to February 2008.

This study is not intended to analyze the complete order and shipping process used within the Navy for IPG-1 requisitions. It is also not intended to critique the operations of the various DoD supply depots or the receipt procedures of the individual destinations, or determine their effects on processing and shipping times. Finally, it is not intended to provide a detailed or in-depth review of the operations of the different carriers and how these operations may impact shipping times.

This study, through the analysis of historical data, is interested first in determining what effect source of supply, carrier, and the interaction between the two, have on processing and shipping times for IPG-1 requisitions to overseas and CONUS Navy locations. Second, this study seeks to determine what source of supply and carrier, if applicable, provides the highest probability of producing the smallest processing and shipping times to various overseas and CONUS destinations. The results and conclusions of this study will assist PMO in revising current procedures and/or producing a new protocol for expediting IPG-1 requisitions.

It is assumed that the data, specifically supply source, material issue processing times, destination, carrier, and shipping times, used for this study are accurate. It is assumed that the processing time as reported includes material release order, processing, picking, and packing; and is the actual time between the date the material release order is received by the supply source and the date of pick-up at the supply source. It is also assumed that the shipping time as reported is the actual time between the date of pick-up at the supply source and the date of delivery at the IPG-1 requisitioner's geographic location. For example, if a carrier picks up an item at Defense Distribution Center San Diego, CA (DDDC) on June 1 and delivers the part to USS FRANK CABLE (AS 40) receipt department in Guam on June 4, the shipping time is three days.

Lastly, it is assumed that all requisitioned items are, for all practical purposes, identical in size, packaging, and ease of shipping. In other words, that there are no special processing or handling requirements that would make sources of supply or carriers incomparable.

D. COURSE OF THE STUDY

This thesis is comprised of five chapters. Chapter II reviews pertinent literature and previous studies relevant to the shipment of high-priority requisitions within the Navy. Chapter III describes the datasets and variables used for the models. It also explains the statistical models and techniques used for the study. Chapter IV consists of preliminary, multivariate ordinary linear models, multivariate generalized linear models, and nonparametric analyses. Chapter V summarizes the conclusions of the analyses and presents recommended areas for further study.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE REVIEW

A. REQUISITIONING PROCEDURES WITHIN THE U.S. NAVY

Requisitioning channels are an essential element of the operational readiness of Navy, Marine Corps and Coast Guard activities and an inextricable part of the DoD integrated supply system. There are two basic methods by which an activity may obtain the materials and services it requires. The first is by submission of a requisition to an ashore supply activity or to another Navy, Marine Corps or Coast Guard unit, and the second is by purchase directly from a commercial source. A unit normally will procure its requirements by submitting a requisition to a Navy or DoD supply activity as specified in current operational orders and instructions issued under the direction of Naval Supply System Command and Fleet Commanders. However, when the supply system is unable to provide material required for immediate operations, the unit's Supply Officer (or service equivalent) is authorized to purchase these requirements directly from a commercial source in the open market, subject to limitations in the Department of the Navy Simplified Acquisition Procedures (SAP) (NAVSUPINST 4200.85 series). (NAVSUP P-485, 1997, p. 3-9).

The Military Standard Requisitioning and Issue Procedures (MILSTRIP) are used for ordering all material from government sources of supply, including the Navy Supply System, the Defense Logistics Agency, and the General Services Administration. MILSTRIP is designed to permit transmission and receipt of requisitions by electronic methods. A MILSTRIP requisition is an established sequence of letters and numbers that includes such information as National Stock Number (NSN), Unit Identification Code (UIC) of requisitioning command, requisition serial number, quantity, Required Delivery Date (RDD) code, and priority code. The media commonly used for submitting requisitions include:

1) Standard Automated Logistic Tool Set (SALTS)

2) Electronic Mail (NIPRNET and SIPRNET E-mail)

3) Web Requisitioning (WebReq)

4) Naval message

5) Telephone, voice, and facsimile (landline and satellite).

Telephone, mail and fax are the most labor-intensive and error-prone methods of submission and consequently tend to be avoided (NAVSUP P-485, 1997, pp. 3-33 to 3-34).

An integral and vital part of the MILSTRIP is the requirement to assign priorities in accordance with standards set forth in the Uniform Material Movement and Issue Priority System (UMMIPS) found in the DoD 4140.1 series. In the movement and issue of material, it is necessary to establish a common basis to determine the relative importance of competing demands for resources of the logistics systems such as transportation, warehousing, requisition processing, and release of material assets. The basis for expressing the military urgency of a requirement is the priority designator (PD), which ranges from 01 (highest) to 15 (lowest). The PD assigned to a requisition determines the time frame within which the requirement normally will be processed by the supply system (NAVSUP P-485, 1997, p. 3-44). Requisitions with PDs 01 through 03 are referred to as Issue Priority Group One (IPG-1) requisitions, which will receive Transportation Priority 1 (TP1) status and are shipped via premium transportation (i.e, air carrier). IPG-1 requisitions have a total order-to-receipt time goal ranging from 6.5 to 11 days for overseas requisitions and 3.5 days for CONUS requisitions (DLA Customer Handbook, 2007, p. III-67). For Navy, Marine Corps or Coast Guard forces based or deployed overseas, IPG-1 requisitions are assigned for all critically needed material which includes Not Operationally Ready Supply (NORS) and Anticipated Not Operationally Ready Supply (ANORS) requirements, as defined in Naval Supply Procedures, Volume I, Afloat Supply (NAVSUP P-485, 1997, p. 3-31). Figure 2.1 provides a basic schematic of the IPG-1 requisitioning and shipping process.

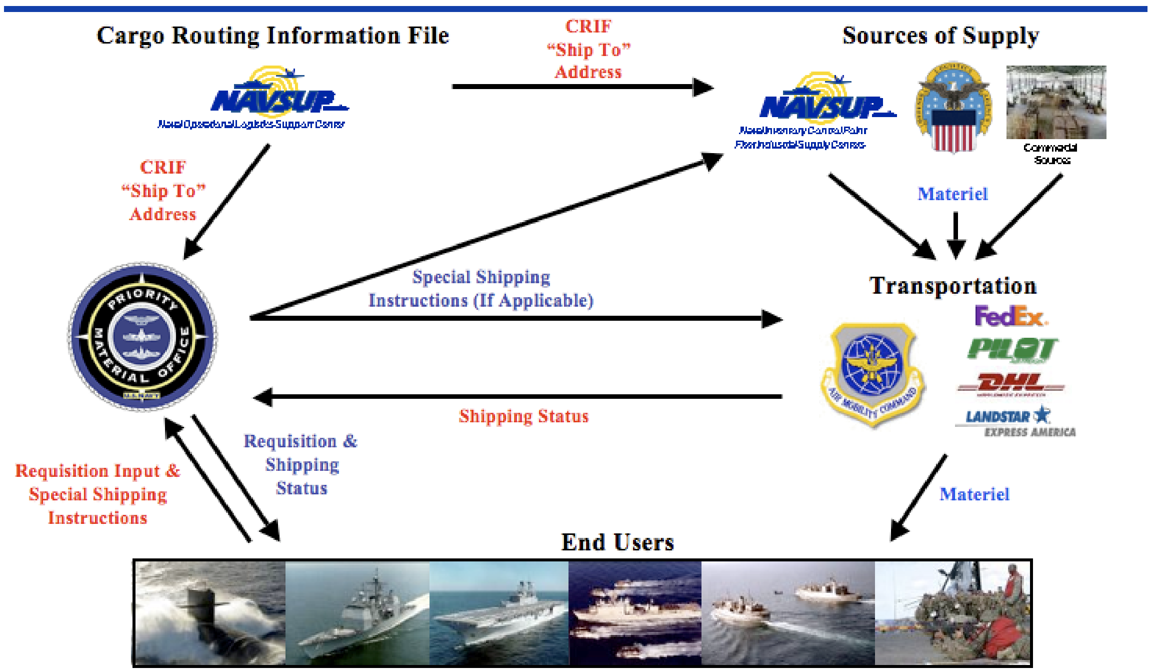


Figure 2.1. Overview of IPG-1 Requisition/Shipping Process (After Haynes, J., *PMO 101*, April 2008)

Further details on MILSTRIP and UMMIPS can be found in the Naval Supply Procedures, NAVSUP P-485 Volume I, Afloat Supply, and the Defense Logistics Agency Customer's Handbook.

Priority Material Office (PMO), Bremerton WA, is the point-of-entry and expeditor for IPG-1 requisitions originating from Pacific and Atlantic Fleet activities, excluding aircraft carriers. In this capacity, PMO maintains accurate, near real-time, in-transit visibility to all customers and decision makers. As the Naval Submarine and Surface Forces (SUBFOR/SURFOR), and Military Sealift Command (MSC) focal point for all NORS and ANORS requisitions, PMO performs assigned material control and supply support responsibilities in support of all Pacific and Atlantic Fleet surface ships, submarines, and other Intermediate Maintenance Activity (IMA) shore Logistics Support Activities, as well as deployed USMC ground forces, various Naval Expeditionary Forces and Naval Special Warfare units, and select U.S. Coast Guard units (Priority Material Office Code 20 Standard Operating Procedures).

B. PRIORITY MATERIAL OFFICE (PMO)

The Priority Material Office (PMO) was initially commissioned Pacific Fleet Polaris Material Office (PMOPAC) on 16 April 1964. It has served since its inception under the operational control of Commander Submarine Force, U.S. Pacific Fleet (COMSUBPAC). Originally established to support the Fleet Ballistic Missile (FBM) submarines and their tenders, its role expanded in 1982 to the entire Pacific Fleet submarine force, both afloat and ashore. In 1994, the command's name was changed to Submarine Logistics Support Center (SUBLOGSUPPCEN). In 1998, PMO's customer base expanded again to include all Pacific Fleet surface ships (with the exception of aircraft carriers) and Military Sealift Command units. In 2000, the command was renamed Priority Material Office (PMO) to better reflect its broader mission and in 2004, AFLSC was merged into PMO. Headquartered in Bremerton, WA, PMO also operates detachments in New London, CT, Norfolk, VA, Kings Bay, GA, San Diego and Travis AFB, CA, Pearl Harbor, HI and Yokosuka, Japan (PMO Command History, 2008).

Currently, PMO receives and expedites approximately 55,000 requisitions annually for a customer base of about 430 activities. PMO's requisitioning customers include Pacific and Atlantic Fleet submarines, surface ships (excluding aircraft carriers), submarine tenders, Military Sealift Command (MSC) ships, deployed USMC ground forces, various Naval Expeditionary Forces, various Naval Special Warfare units, select U.S. Coast Guard units, Intermediate Maintenance Facilities (Puget Sound, WA and Pearl Harbor, HI), and Ship Repair Facilities (Guam, Yokosuka and Sasebo).

To expedite IPG-1 requisitions, PMO maintains and utilizes the Integrated Supply Information System (ISIS), a web-enabled requisition tracking system. ISIS has a web interface for two different applications. The ISIS Online application is used by PMO's customers for requisition input, tracking, reporting and status. The ISIS Web Expediting Tool is used internally by PMO and its detachments. (PMO, [https://www.pmohq.navy.mil/ISIS.aspx], 2008).

ISIS is used by both the Pacific and Atlantic Fleets. Developed and programmed by PMO, ISIS stores information in an Oracle database for later extraction using real-time inquiries and reports. ISIS can be accessed via the Internet. ISIS is the tool that allows PMO to provide its customers with plain language status and in-transit visibility of their requisitions. Status can also be obtained from the PMO command web site. For customers with Internet connectivity, requisitions can be input directly into the PMO database using the ISIS Online function. ISIS also has automated links to military and civilian databases to ensure customers have the latest information. (PMO Command History, 2008)

As the most mission critical application for PMO, ISIS is available at all times to provide timely and accurate reporting and processing capability. ISIS maintains accurate, real-time, and in-transit visibility to all customers and decision makers by tracking every step the requisition goes through and providing real time status updates. It was designed to allow multiple remote sites to connect to central resources to track, manage and issue material requisitions. Users log into the system to prepare or check the status of requisitions. ISIS interacts with multiple supply databases to provide the most accurate data in the timeliest manner. Requisition Status Reports are automatically generated and emailed via ISIS to customers on a regular basis.

PMO has several divisions responsible for the various stages of the requisition process. The two primary divisions of concern in this thesis are Point-of-Entry (POE) and Shipping. Some of the main responsibilities of the POE division include:

- Receipt of all incoming IPG-1 requisitions;
- Conducting asset checks of DoD supply systems to locate required material through one of the primary electronic interfaces which include the Naval Supply Systems Command “One Touch Support” (OTS) website, Defense Logistics Agency “Asset Visibility” (AV) website and the Real Time Reutilization Asset Management System (RRAM);
- Forwarding requisitions via facsimile, telephone, or electronically (e-mail/direct interface) to Navy or DoD supply depots which have required material in stock;

- Providing special shipping instructions or updated shipping addresses to source of supply;
- Monitoring and expediting requisitions until material is shipped, and updating ISIS with status of requisitions;
- Sending updates to customers with requisitions status.

Some of the main responsibilities of PMO's Shipping Division include:

- Arranging expeditious transportation using freight forwarders when standard premium transportation is insufficient to support operational schedules;
- Monitoring and expediting requisitions during shipment;
- Reconciling requisition receipts and updating ISIS (Commanding Officer, PMO, February 2008).

In deciding the best source of supply for a requisition, PMO's current procedures recommend choosing the DoD distribution depot that can completely satisfy the requirement (i.e, has the full quantity requested) and that is physically closest to the customer's location. For example, suppose an IPG-1 requisition needed to be shipped to USS FRANK CABLE (AS 40), homeported in Guam, and the required material is available at distribution depots in San Diego, CA and Norfolk, VA. PMO would select the distribution depot in San Diego because it is geographically closer to Guam than Norfolk (Commanding Officer, PMO, February 2008). When an item is not available in the supply system (i.e., DLA or Naval Inventory Control Point), alternative sources of supply may include Force Inventory Management Analysis Reporting System (FIMARS) screens and directives, system cannibalizations, and commercial purchases.

Naval Supply Systems Command (NAVSUP) Headquarters maintains a centralized database providing total asset visibility of retail and end-use material located at afloat activities. Afloat Total Asset Visibility (ATAV) databases, including the FIMARS application, is available through NAVSUP's 'One Touch Support' (OTS) system. OTS provides on-line inventory visibility by National Item Identification

Number (NIIN) and access to FIMARS WEB ATAV. This visibility is crucial to supply system responsiveness by ensuring that high priority requirements can be satisfied under limited stockage conditions. Accordingly, the database must be regularly maintained by all activities by processing Force Inventory Transmission System (FITS) downloads. Regular updates help to ensure visibility of inventory range and depth of all Fleet activities. FIMARS WEB ATAV can be queried by material expeditors and all fleet activities in their attempts to fill outstanding material requirements which are not held locally (NAVSUP P-485, 1997, p. 6-25). PMO is authorized by COMNAVSURFOR, COMNAVSURFLANT, COMSUBFOR, and COMSUBPAC to direct ship-to-ship material transfers to fill critical requisitions when supply system assets are not readily available.

Real Time Reutilization Asset Management System (RRAM) is a real-time inventory of residual and Sponsor Owned Material (SOM) assets that are neither retail nor wholesale. It promotes asset reutilization, resulting in major cost avoidances and may provide free issue to the fleet; results in procurement and repair offsets for NAVICP/DLA; and conducts backorder reviews while maintaining SOM. RRAM has been implemented in warehouses that receive material which is deemed to be excess to the needs of the owner. The owner is usually a Type Commander or a Hardware System Command. Generally, the material is excess as a result of design changes, ship de-commissioning or allowance reductions. In the past it was referred to as "Goldpiles." The RRAM LAWSON Insight II application is used to manage receipt, storage, and issue of material from these warehouses. RRAM also provides visibility of material in these warehouses, thereby contributing to the Navy's Total Asset Visibility goal. RRAM provides order processing functionality to reutilize existing assets, helps fleet units stretch their Operating Target (OPTAR, or annual operating funds), lowers warehousing/storage bills, prevents waste, lowers costs to U.S. taxpayers, and allows Inventory Control Points (ICPs) to get assets faster to fill customer requirements.

There are three classes of inventory in RRAM. The first class is the initial RRAM Free Issue inventory. These items are normally free to the user. Some inventories in this class can be restricted to specific UICs. The second class is Sponsor Owned Material

(SOM). This is material located at an activity that is marked for a specific project. The owner may or may not sell the item. Issue of items is strictly controlled by the owner. Exchange of funds is external to RRAM. The third class is a Virtual File of SOM. This is a snapshot of selected inventory items for which an activity wants to have Total Asset Visibility. RRAM does not manage these inventories so the owner (Point of Contact) must be contacted to request these items. All issue/shipping transactions are performed external to RRAM through the local site's warehouse management system (NAVSUP RRAM Brief for FSPC/ESPC, May 2006).

For commercial purchases, the Technical/Purchasing section of PMO searches various systems for technical specifications and vendors for the requirement. The Technical/Purchasing section then contacts vendors via phone or e-mail to obtain quotes. Sourcing decision factors include speed of delivery, cost to deliver, location of originator, location of deliverer, required delivery date and priority of the part (PMO Command Brief, February 2008).

For carrier selection, PMO primarily requests distribution depots to ship IPG-1 requisitions by the fastest traceable means via one of the following: Federal Express® (FedEx®), DHL Worldwide Express® (DHL®), United Parcel Service, Inc. ® (UPS®), Air Mobility Command (AMC) or commercial freight forwarders. Figure 2.2 provides a simple flowchart of how PMO processes IPG-1 requisitions.

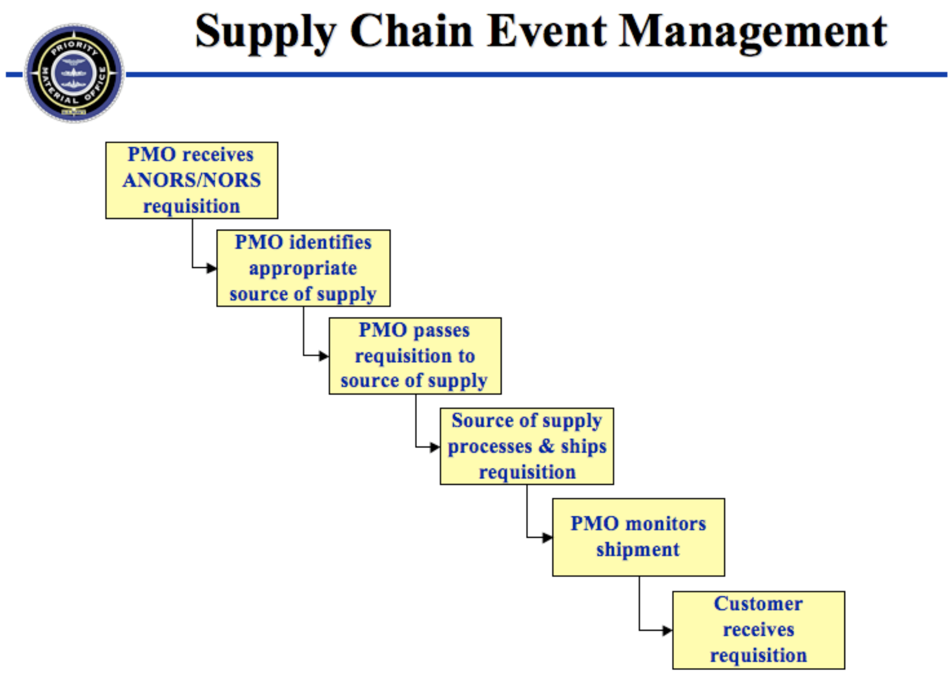


Figure 2.2. PMO IPG-1 Requisition Process Flowchart (After Haynes, J., *PMO 101*, April 2008)

Naval Logistics Integration (NLI) is a Chief of Naval Operations (CNO)/Commandant of the Marine Corps (CMC) initiative designed to integrate logistics components and processes of the Navy and Marine Corps. Designated as the "Common Expediting Organization," PMO was institutionalized for use by deployed Marine Expeditionary Units (MEUs) in October of 2006. By October 2007, PMO had begun expediting for the Supply Management Unit at al Taqqaram (SMU TQ) customers in Iraq. NLI additionally provides the foundation for expediting for the Naval Expeditionary Forces (NEF) and Naval Special Warfare (SPECWAR) communities. As of early 2008, Naval Mobile Construction Battalions (NMCBs) 40 and 133 and Naval Special Warfare Group THREE (NSWG-3) were already utilizing PMO (PMO Command Brief, February 2008).

C. PREVIOUS STUDIES

A literature review was conducted in order to find the results of relevant research that has been done on the effect of supply source and carrier on shipping times for IPG-1 requisitions within the Navy. This literature research includes a study by Vickers (1997) pertaining to shipping times for requisitions within the Pacific Air Force, as well as a study by Schorn (2003) pertaining to supply source and shipping times for requisitions processed by PMO that, due to PMO's charter at the time of research, did not include Sixth Fleet units, continental United States (CONUS) sites, deployed USMC ground forces, Naval Expeditionary Forces, Naval Special Warfare units, U.S. Coast Guard units, AMC, commercial freight forwarders, FIMARS or RRAM.

Vickers analyzed and compared the shipment of reparable assets from the Air Force's Support Center Pacific (SCP), Kadena Air Base, Japan, and from CONUS Air Force repair activities to the various Western Pacific (WESTPAC) Air Force bases (Misawa and Yokota Air Bases in Japan, and Kunsan and Osan Air Bases in Korea). The purpose of the research was to determine:

1) Whether mean shipping times between SCP and the Air Force bases in the Western Pacific were smaller than mean shipping times for shipments from CONUS to those bases; and

2) Whether commercial express air carriers, specifically FedEx, produced significantly smaller mean delivery times than the Defense Transportation System (DTS) for shipments between SCP and WESTPAC Air Bases.

The data analyzed included two sets of sample shipping times for IPG-1 Air Force requisitions for WESTPAC Air Bases from July 1995 through January 1997, one dataset for requisitions shipped from SCP and the other dataset for requisitions shipped from CONUS repair facilities. The following assumptions were made: 1) the two samples were randomly selected in an independent manner and, 2) the sample sizes were large enough so that the sample means had approximately a normal distribution. The combined sample sizes Vickers used in his analysis ranged from 191 to 3,223 observations. The Central Limit Theorem supported the second assumption.

Based on these assumptions, Vickers applied large-sample "*z*-test" procedures and corresponding hypothesis tests. The null hypothesis that "there is no difference between mean shipping times for shipments originating from CONUS and mean shipping times for shipments from SCP" was tested against the alternative hypothesis that "there is a difference in the mean shipping times."

Similarly, *z*-test procedures were used to determine if there was a difference between the mean shipping time of requisitions shipped through the DTS and the mean shipping time of requisitions shipped via FedEx. The null hypothesis in this case was "there is no difference between the mean shipping times of DTS and FedEx shipments" and the alternative hypothesis was "there is a difference in the mean shipping times."

For both test cases the null hypothesis was rejected in favor of the alternative hypothesis at a significance level of 0.01 ($\alpha = 0.01$). Based on these results it was concluded that the shipping times for requisitions from SCP to WESTPAC Air Force bases were shorter than shipping times for requisitions from CONUS; therefore SCP was the preferred source of supply for WESTPAC air bases. It was also concluded that the shipping times for requisitions carried by FedEx was significantly smaller than the shipping times for requisitions carried by the DTS; thus, a commercial carrier was the better choice for shipping IPG-1 requisitions. Vickers' study supports the notion that source of supply and carrier may impact shipping times for high-priority requisitions.

Schorn examined the impact of source of supply and carrier on shipping times of IPG-1 requisitions to the primary overseas destinations of U.S. Navy units operating in the Pacific Theater and the Persian Gulf. The data used in this study was taken from the Priority Material Office's requisition database for the period October 1999 to November 2002. Destinations included in the study were Guam, Bahrain, Singapore, Okinawa, Sasebo, and Yokosuka.

Schorn's analysis was limited to primary sources of supply for IPG-1 requisitions. For his study, a primary source of supply was defined as a single DoD or Navy supply center, or a group of DoD and Navy supply activities within a single geographic location (e.g. Fleet and Industrial Supply Center, San Diego, and Defense Distribution Center, San Diego) that shipped at least 200 IPG-1 requisitions during the three-year period of the historical requisition data. Federal Express® (FedEx®) and DHL Worldwide Express® (DHL®) were the only carriers included in the analysis.

Ordinary least squares (OLS) models were deemed inadequate to analyze the historical requisition data due to non-normal error distributions. However, Poisson generalized linear models (GLMs) provided valid models from which results could be gleaned. GLMs were utilized to explain and explore the effect of source of supply and carrier on shipping times. The results indicated that source of supply had a statistically significant effect on high-priority requisition shipping times, while carrier did not. Additionally, GLMs showed that there was no significant interaction between the two variables. The smallest observed mean shipping times ranged from approximately 3.25 days to 4.00 days, while the largest observed mean shipping times ranged from approximately 4.75 days to 6.75 days.

Nonparametric Kruskal-Wallis rank sum test results supported the GLM results. Specifically, this nonparametric test provided statistical evidence that source of supply had an effect on shipping times to all destinations with the exception of Okinawa. The nonparametric results also indicated that carrier did not have a significant effect on shipping times, i.e., the two carriers included in the study were determined to have indistinguishable mean shipping times.

III. DATA AND METHODOLOGY

A. DATASETS

The data used in this study was provided by the Priority Material Office (PMO). PMO provided three years of shipping data for IPG-1 requisitions, dated from February 2005 to February 2008. The data included nineteen variables for each shipment: Document Number, Date Received, Pass to Date, Pass to RIC (Routing Identifier Code), Ship Date, Ship From (RIC), Ship To (RIC), Carrier, BA Date, BA RIC, BB Date, BB RIC, BZ Date, BZ RIC, BV Date, BV RIC, Destination RIC From, Destination RIC To, and Destination Date. For this study, the columns of interest included Pass To Date (date of supply expediting process initiation, when the requisition was passed to the source of supply), BA RIC (source of supply, or major DoD distribution center which processed the requisitioned item for release and shipment), Ship Date (date that the carrier picked up the requisitioned item at a supply source), Carrier (primary air carrier, AMC or commercial freight forwarder), Destination RIC To (major overseas or CONUS supply destination), and Destination Date (date that the item arrived at the requisitioning activity's geographic location).

The original dataset consisted of 95,405 requisitions. This original dataset was refined by removing data that were incomplete, erroneous, or not applicable to this study. Of these, 8,583 requisitions (approximately 9%) were missing essential data and were consequently omitted. In some cases, the BA RIC (i.e., source of supply) data was not filled in because the requisitioned item was out of stock. In these cases, the requisitioning activity either placed the item on back order or procured the item commercially for direct shipment. This data was therefore outside the range of this study. Next, 1,026 requisitions were determined to be erroneous because of negative processing and/or shipping times, and were deleted.

Once incomplete and erroneous data were removed from the dataset, the final step in refining the dataset was to determine primary supply sources, carriers and destinations. For this study, a primary supply source was defined to be an individual DoD distribution depot (e.g, Defense Distribution Depot Susquehanna, PA (DDSP)) or a group of DoD supply activities within a single geographic locale (e.g, Fleet & Industrial Supply Center (FISC) San Diego, CA and Defense Distribution Depot San Diego, CA (DDDC)) that shipped at least 200 IPG-1 requisitions to overseas and CONUS destinations within the time frame of the historical data, or was otherwise of interest to PMO. The names and locations of the primary supply sources are provided in Table 3.1. Similarly, a primary carrier was defined to be an air carrier or commercial freight forwarder that transported at least 200 IPG-1 requisition items to overseas and CONUS destinations within the time frame of the historical data, or was otherwise of interest to PMO. The names of primary carriers are provided in Table 3.2. A primary destination was defined to be an overseas or CONUS geographic location that either received at least 200 IPG-1 requisitions within the time frame of the historical data, or one which received especially critical requisitions. Geographic locations rather than individual commands were used for destinations because individual command destinations are generally located within a single geographic locale, and the intent of this study was not to analyze the effect of individual command destinations on shipping times. There were eleven primary overseas destinations (Atsugi, Bahrain, Guam, Hong Kong, Mildenhall (UK), Okinawa, Rota, Sasebo, Sigonella, Singapore, and Yokosuka) and eight primary CONUS destinations (Bangor/Bremerton, Everett, Groton, Kings Bay, Mayport, Norfolk, Pearl Harbor, and San Diego) that were analyzed in this study. Using these criteria to select primary sources of supply, carriers and destinations, another 56,754 requisitions were deleted. After this refining process, the final dataset used in this study consisted of 29,042 requisitions.

For the purpose of this study, it was assumed that the time required for a source of supply to process a requisition was not affected by either the carrier selected or the destination location. Thus, processing time was not analyzed individually for each destination area and the complete dataset of 29,042 requisitions was used in this particular analysis.

It was also assumed that selected carriers and customer destinations could have an effect on the time required to ship a requisition from a source of supply. Consequently, the dataset of 29,042 requisitions was then divided into 19 subsets (one subset per primary destination). These 19 data subsets were analyzed individually by carriers, and a unique shipping time model was developed for each of them. Thus, geographic destination is an implicit explanatory variable within each of these models.

B. VARIABLE INTRODUCTION

The models used for this study will have two dependent variables: PROCESSING TIME and TOTAL SHIPPING TIME (calendar days); and two independent variables (or explanatory factors): SOURCE OF SUPPLY and CARRIER. For each requisition, PROCESSING TIME is equal to the difference between the ‘Pass to Date’ entry and the ‘Ship Date’ entry, while TOTAL SHIPPING TIME is equal to the difference between the ‘Pass to Date’ entry and the ‘Destination Date’ entry. Although ‘Pass To Date,’ ‘Ship Date,’ and ‘Destination Date’ column entries in the provided dataset contain dates and times, this study was primarily interested in differences between the respective dates only. Thus, PROCESSING TIME and TOTAL SHIPPING TIME were mainly expressed as integers with values greater than zero. In the instances where requisition processing or delivery was completed in less than a day, a value of 0.3 was assigned (instead of zero). This made it possible to perform logarithmic transformations on the datasets. Tables 3.1 and 3.2 provide listings of the explanatory factors.

Name (Level)	Description
DDAA	Defense Distribution Depot Anniston, AL
DDAG	Defense Distribution Depot Albany, GA
DDBC	Defense Distribution Depot Barstow, CA
DDCN	Defense Distribution Depot Cherry Point, NC
DDCO	Defense Distribution Depot Columbus, OH
DDCT	Defense Distribution Depot Corpus Christi, TX
DDDC	Defense Distribution Depot San Diego, CA FISC San Diego, CA
DDDE	Defense Distribution Depot Europe, Germany
DDHU	Defense Distribution Depot Hill, UT
DDJC	Defense Distribution Depot San Joaquin, CA
DDJF	Defense Distribution Depot Jacksonville, FL FISC Jacksonville, FL
DDNV	Defense Distribution Depot Norfolk, VA FISC Norfolk, VA
DDOO	Defense Distribution Depot Oklahoma City, OK
DDPH	Defense Distribution Depot Pearl Harbor, HI FISC Pearl Harbor, HI
DDPW	Defense Distribution Depot Puget Sound, WA FISC Puget Sound, WA
DDRT	Defense Distribution Depot Red River, TX
DDRV	Defense Distribution Depot Richmond, VA
DDSI	Defense Distribution Depot Sigonella, IT DLA Sigonella, IT FISC Sigonella, IT
DDSP	Defense Distribution Depot Susquehanna, PA
DDTP	Defense Distribution Depot Tobyhanna, PA
DDWG	Defense Distribution Depot Warner Robins, GA
DDYJ	Defense Distribution Depot Yokosuka, Japan FISC Yokosuka, Japan
N66	TRF Bangor
P64	NWSC Crane, IN

Q6R	TRF Kings Bay, GA
R7R	USS EMORY S LAND (AS 39)
R7U	USS FRANK CABLE (AS 40)

Table 3.1. Explanatory Factors: Source of Supply (DLA, 2007, pp. I-42 to I-47)

TOTAL SHIPPING TIME was selected as a dependent variable rather than simply the time from 'Ship Date' to 'Destination Date' for the following reasons. First, it is reasonable to assume that between the time that a source of supply completes processing of its requisition, to the time that a carrier picks up the requisitioned part, there exists a waiting period. While the period between 'Ship Date' and 'Destination Date' does not account for this period, TOTAL SHIPPING TIME does. Thus, if a certain carrier's policy is to optimize the number of pick-up/delivery runs in a given area only when a minimal number of stops is met, or if a carrier's pick-up/delivery hours ends at an earlier time than other carriers, or if a carrier has a longer distance to travel to the source of supply, this delay is accounted for. The second reason for choosing this independent variable is that this time is what PMO and its customers are primarily interested in, i.e., how long they must wait before receiving the requisitioned item. Thus, TOTAL SHIPPING TIME was selected as a key performance metric.

Name (Level)	**Description**
AMC	Air Mobility Command
DHL	DHL
FEDEX	FEDEX
UPS	United Parcel Service, Inc.
LANDSTAR/MAC	LANDSTAR / Military Air Cargo
CCGL	CC GLOBAL
PILOT AIR	PILOT AIR
NATIONAL AIR CARGO	NATIONAL AIR CARGO

Table 3.2. Explanatory Factors: Carrier

C. METHODOLOGY

1. Ordinary Least Squares (OLS) Linear Regression

a. Bivariate Regression Analysis

Bivariate regression analysis seeks the line or curve that best fits a scatter of data to describe the relationship between a dependent (outcome or response) variable and an independent (predictor or explanatory) variable. The most widely used regression technique, ordinary least squares (OLS), defines the "best fitting" line by obtaining coefficient estimates that minimize the sum of squared residuals. The popularity of OLS stems from its simplicity and widely demonstrated practical value, as well as from its theoretical advantages over other estimators under ideal conditions (normal independent and identically distributed (i.i.d.) errors (Hamilton, 1992, pp. 58-59, 101).

One quantity of interest in a regression model is the mean value of the outcome variable, given the value of the independent variable. Bivariate regression models view the expected value of *Y* as a linear function of *X*:

$$E[Y_i] = \beta_0 + \beta_1 X_i$$

The actual *Y* is equal to the expected *Y* plus a random error:

$$Y_i = E[Y_i] + \varepsilon_i .$$

The specific form of the bivariate regression model used in this study is: $Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$. In this study, Y_i represents the PROCESSING TIME variable and X_i represents the SOURCE OF SUPPLY factor variable (X_i represents the *i*th value of the *X* variable) (Hamilton, 1992, p. 31). This model was applied using the complete useable dataset of 29,042 requisitions.

b. Multivariate Regression Analysis

Multivariate regression analysis seeks the line, curve, or hyperplane that best fits a multi-dimensional scatter of data to describe the relationship between a dependent (outcome or response) variable and a set of independent (predictor or explanatory) variables. The most widely used regression technique, ordinary least squares (OLS), defines the "best fitting" line by obtaining coefficient estimates that minimize the sum of squared residuals (Hamilton, 1992, pp. 58-59, 101).

Multivariate regression models view the expected value of *Y* as a linear function of (*K*-1) *X* variables:

$$E[Y_i] = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \ldots + \beta_{K-1} X_{i,K-1}$$

where *K* stands for the number of parameters (β's) in the model, usually one more than the number of *X* variables. The specific form of the multiple regression model used in this study, which included interaction effects, is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i1} X_{i2} + \varepsilon_i .$$

In this study, Y_i represents the SHIPPING TIME variable, X_{i1} represents the SOURCE OF SUPPLY factor variable, X_{i2} represents the CARRIER factor variable, and $X_{i1}X_{i2}$ represents the interaction between these two variables (X_{i1} and X_{i2} represent the *i*th values of variables X_1 and X_2) (Hamilton, 1992, p. 66).

In order to reduce the effects of the positive skewness and outliers, a natural logarithm transformation, denoted by "log," was applied to the dependent variable *Y*, producing the following model: $\log(Y_i) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i1} X_{i2} + \varepsilon_i$. This model was applied using the 19 individual data subsets, one for each primary destination.

c. *Linear Model Validation*

There are several assumptions that must be checked to determine if the OLS models are valid. These assumptions include:

- Fixed *X*, where many random samples could be (in principle) obtained, each with the same *X* values but different Y_i, due to different ε_i values;
- Errors have zero mean;
- Errors have constant variance (homoscedasticity);
- Errors are uncorrelated with each other (no autocorrelation);
- Errors are normally distributed ($\varepsilon_i \sim N(0, \sigma^2)$ for all *i*).

As our analysis was primarily interested in using analysis of variance (ANOVA) *F*-tests to determine the effects of the factor variables, including interaction, the assumption that errors are normally distributed was the first to be tested. Non-normal error distributions reduce the efficiency of OLS and invalidate *F*-tests. (Hamilton, pp. 110-112) This assumption was checked by examining the Quantile-Normal plot of each model's residuals. If this plot clearly indicated that the errors were not normally distributed, the model was rejected in favor of a generalized linear model (GLM) that is discussed in the following paragraphs. If a model's residuals did follow a normal distribution, the other assumptions were checked for validity. If the linear model was deemed adequate, it was used to make inferences regarding the effect of the explanatory variables on the outcome variable. See Chapter IV, Section B, for the results.

2. Generalized Linear Models (GLM)

a. Poisson GLM

Generalized linear models are an extension of ordinary linear models that allow for modeling data with distributions of $Y_i|X_i$ that are not normal. As with OLS, GLM regression analysis seeks the line, curve, or hyperplane that best fits a scatter of data to describe the relationship between a dependent (outcome or response) variable and a set of independent (predictor or explanatory) variables. GLMs include, as special cases, linear regression and analysis-of-variance models, logit and probit models, log-linear models and multinomial response models. These models share a number of properties, such as linearity, that allow for the studying of generalized linear models as a single class, rather than as an unrelated collection of special topics. While ordinary linear models are only valid under the assumption of a normal distribution of errors, many of the important properties of least squares estimates depend not on normality, but on the assumptions of constant variance and independence. Similarly, the second-order properties of GLMs depend mainly on the assumed variance-to-mean relationship and on uncorrelatedness or independence. This is particularly useful because in many applications, the validity of an assumed distributional form may be questionable. (McCullagh and Nelder, 1989, pp. 1-2).

A GLM provides a way of estimating a function of the mean response as a linear combination of some set of predictors and can be expressed as the link function:

$$g(\mu_i) = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ij} = \eta(x_{ij}), \qquad (\forall i)$$

where $\mu_i = E(Y_i)$, x_{ij} is the *i*th observation of the *j*th explanatory variable, β_0 is the intercept, β_j is the coefficient parameter of the *j*th explanatory variable, and $\eta(x_{ij})$ is the linear predictor. The variance of the outcome variable, *Y*, may be written as:

$$\mathrm{var}(Y) = a(\phi)V(\mu),$$

where $V(\mu)$ is the variance function, and $a(\phi)$ is the weighted dispersion parameter of ϕ (also denoted by σ^2) which may be expressed as $a(\phi) = \phi/w$, or σ^2/w (McCullagh and Nelder, 1989, pp. 26-29).

The Poisson distribution was developed as a way to deal with discrete, or rare, events rather than with continuously varying quantities. This has been applied to diverse kinds of events; a famous example concerns unfortunate soliders kicked to death by Prussian horses. Routine laboratory applications of the Poisson model include the monitoring of radioactive tracers by emission counts, as well as counts of infective organisms as measured by the number of events observed on a slide under a microscope (McCullagh and Nelder, 1989, p. 2). Additionally, Poisson models have been applied to simulate future naval aviation flight mishaps to predict the human error characteristics attributable to these mishaps (Denham, 2000, p. 24).

For this analysis, a Poisson GLM appeared to be the most appropriate model since the response variables, PROCESSING TIME and SHIPPING TIME, were discrete with non-negative, and mainly integer values. The Poisson GLM probability mass function (where μ is equal to the mean and variance of *Y*) is expressed as:

$$p(y,\mu) = \frac{e^{-\mu}\mu^{y}}{y!}, \qquad \text{for } y = 0,1,2,\ldots$$

The canonical link for a Poisson distribution is g(μ) = log μ for which the dispersion parameter ϕ is equal to one, and the variance function is $V(\mu) = \mu$. The resulting GLM is:

$$g(\mu_i) = \log(\mu_i) = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ij} = \eta(x_{ij}) .$$

The maximum likelihood method is commonly used to estimate the parameters in a GLM and to assess the precision of the estimates. For a given probability distribution specified by $f(y;\mu)$ and observations $y = (y_1,\ldots,y_n)$, the log-likelihood function for μ, expressed as a function of mean values of the responses $\{Y_1,\ldots Y_n\}$ has (up to a constant) the form:

$$l(\mu_1,...,\mu_n; y_1,..., y_n) = \sum_{i=1}^{n} \log f_i(y_i;\mu_i) .$$

The Poisson log-likelihood function is:

$$l(\mu_1,...,\mu_n; y_1,..., y_n) = \sum_{i=1}^{n} (y_i \log \mu_i - \mu_i) .$$

(McCullagh and Nelder, 1989, pp. 24-32, 197)

The maximum likelihood estimates of the parameters μ can be obtained by the iterative re-weighted least squares (IRLS) process (Chambers and Hastie, 1991, pp. 242-243). Detailed information about the iterative algorithm and asymptotic properties of the parameter estimates can be found in McCullagh and Nelder (1989).

b. Analysis of Deviance

Analogous to the residual sum of squares in linear regression, the residual deviance can be used to measure the goodness-of-fit of a GLM. It is defined by:

$$D(y_1,..., y_n; \hat{\mu}_1,...,\hat{\mu}_n) = 2[l(\mu^*; y) - l(\hat{\mu}; y)],$$

where $l(\mu^*;y)$ is the maximum likelihood achievable for an exact fit in which the fitted values are equal to the observed values, and $l(\widehat{\mu};y)$ is the log-likelihood function calculated at the estimated parameters μ. The Poisson deviance function is given by:

$$D(y_1,...,y_n;\widehat{\mu}_1,...,\widehat{\mu}_n)=2\sum_{i=1}^{n}y_i\log(y_i/\widehat{\mu}_i),$$

where $\widehat{\mu}_i$ is an estimate of $E(Y_i)=\mu_i$ (McCullagh and Nelder, 1989, pp. 24, 197).

The deviance function is useful for comparing two models when one model's parameters are a subset of the second model's. The deviance is additive for such nested models if maximum likelihood estimates are used. (McCullagh and Nelder, 1989, pp. 33-34) Consider two nested models with the second having some explanatory factors omitted and denote the maximum likelihood estimates in the two models by $\widehat{\mu}_1$ and $\widehat{\mu}_2$, respectively. Then the difference in deviance $\{D(y;\widehat{\mu}_2)-D(y;\widehat{\mu}_1)\}$ is identical to the likelihood-ratio statistic and under the null hypothesis has an approximate χ^2 distribution with degrees of freedom equal to the difference between the numbers of parameters in the two models. These approximations can be inaccurate in small sample sizes, but the difference in deviance between two models can be useful as a screening device (Chambers and Hastie, 1991, p. 244).

Given a sequence of nested models, the deviance can be used as the generalized measure of discrepancy and an analysis of deviance table can be created by determining the differences of the models' deviances. Similar to an analysis of variance table in ordinary linear regression, the analysis of deviance table is used to determine what explanatory factors affect the outcome variable. Specifically, the significance (p-value) of the χ^2 statistic is used in deciding what factors have a significant effect on the outcome variable (McCullagh and Nelder, 1989, p. 36). See Chapter IV, Section C, for the results.

3. Nonparametric Statistical Analysis

a. Permutation Test for Regression

Significance tests describe whether an observed effect, such as a correlation between two variables, could reasonably occur "just by chance" in selecting a random sample. If not, evidence exists that the effect observed in the sample reflects an effect that is present in the population (Hesterberg, Moore, Monaghan, Clipson, and Epstein, 2005, p. 14-46).

The statement that an effect is not present in the population is the null hypothesis. The *p*-value of a statistical test is calculated from the sampling distribution the statistic would have if the null hypothesis were true. It is the probability of a result at least as extreme as the value actually observed (Hesterberg, Moore, Monaghan, Clipson, and Epstein, 2005, p. 14-47).

In an effort to support the OLS and GLM analyses, permutation tests for regression were performed on the data. A permutation test (also known as a randomization test), is a type of statistical significance test in which a reference distribution is obtained by calculating all possible values of the test statistic under rearrangements of the labels on the observed data points. If the labels are exchangeable under the null hypothesis, then the resulting tests yield exact significance levels from which confidence intervals can be derived. Often only a sample of rearrangements is generated.

While permutation tests exist for any test statistic (regardless of whether or not its distribution is known), they are based on the assumption that the observations are exchangeable under the null hypothesis (Wikipedia, [http://en.wikipedia.org/wiki/Resampling_(statistics)], 2008).

b. Friedman Test

Another nonparametric statistical test that was applied to the data was the Friedman test. The Friedman test is a nonparametric rank test analogous to ANOVA and the Kruskall-Wallis test, that is robust to the presence of outliers, and does not require the distribution of the sample data to be normal or the variances to be equal. The Friedman test compares column effects in a two-way layout. It is similar to the classical balanced two-way ANOVA, but tests only for column effects after adjusting for possible row effects. It does not test for row effects or interaction effects. Friedman's test is appropriate when columns represent treatments that are under study, and rows represent blocks that need to be taken into account but are not of particular interest. The matrix below illustrates the format for a column factor of three levels and a row factor of two levels. The subscripts indicate row and column, respectively.

$$\begin{pmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \end{pmatrix}$$

Friedman's test assumes a model of the form $x_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$ where μ is an overall location parameter, α_i represents the column effect, β_j represents the row effect, and ε_{ij} represents the error. This test ranks the data within each row, and tests for a difference across columns. If the *p*-value for the null hypothesis that α_i = 0 is near zero, it suggests that at least one column-sample median is significantly different from the others, i.e., there is a main effect due to the row factor.

Friedman's test makes the following assumptions:

- All data come from populations having the same continuous distribution, apart from possibly different locations due to column and row effects;
- All observations are mutually independent.

The first assumption replaces the stronger two-way ANOVA assumption that data come from normal distributions. (The Mathworks, [http://www.mathworks.com/access/helpdesk/help/toolbox/stats/index.html?/access/helpdesk/help/toolbox/stats/friedman.html], 2008).

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS

A. PRELIMINARY DATA ANALYSIS

A preliminary review of the data indicated that in certain instances, the mean PROCESSING TIMES for each SOURCE OF SUPPLY, and the mean SHIPPING TIMES for CARRIERS in each destination data subset were noticeably different. Figure 4.1 shows the range of PROCESSING TIMES for each SOURCE OF SUPPLY, collectively taking into account all destination areas. For the purpose of this study, it was assumed that PROCESSING TIME was not affected by CARRIER or customer destination. Thus, destination areas were not analyzed individually for PROCESSING TIME and the complete dataset of 29,042 observations was used. Outliers in the 29,042 observations included 478 processing times greater than 50 days (1.6%), 241 processing times greater than 100 days (0.8%), and 50 greater than 200 days (0.2%). A number of these could be attributed to times to acquire commercial contracts for parts not readily available in the supply inventory. Although not uncommon in the expediting process, these outliers increased the amount of variation present in some SOURCE OF SUPPLY datasets.

Similarly, plots of TOTAL SHIPPING TIMES for primary CARRIERS to each of the 19 primary destinations displayed a varying degree of variation. The following sections discuss the statistical evidence for the two explanatory variables having an effect on shipping times through the analysis of multivariate OLS models, generalized linear models, and nonparametric tests.

B. OLS LINEAR MULTIVARIATE ANALYSIS

Multivariate modeling measures the effects of independent variables on the response variable by holding constant the effects of the other variables. Ordinary linear models that included factor variables were fitted to the 20 datasets (the complete dataset for PROCESSING TIME analysis, plus its 19 subsets for the analysis of TOTAL SHIPPING TIME to each of the 19 primary destination locations). To reduce the effects of outliers, the response variables (PROCESSING TIME and TOTAL SHIPPING TIME) were transformed using the natural log function.

The software package S-Plus 8.0® was used to estimate and validate OLS regression models. Prior to developing ordinary least squares linear regression models, the OLS model assumptions were tested for validity. Specifically, Quantile-Normal plots of each model's residuals were used to determine if the errors were normally distributed. If the errors were not normally distributed, the ordinary linear model was rejected. Appendix A contains the Quantile-Normal plots for residuals of the PROCESSING TIME model, and the 19 TOTAL SHIPPING TIME models for each of the primary destination areas. Plots for each dataset clearly illustrate heavy tails and high outliers, which are indicative of non-normal residual distributions. Thus, the OLS linear models were rejected in favor of the GLMs.

C. GLM MULTIVARIATE ANALYSIS

As with the OLS linear models, S-Plus® was used to estimate GLMs for each of the 20 datasets. Because the response variables PROCESSING TIME and TOTAL SHIPPING TIME were discrete, this study used Poisson GLMs with a log link function. A stepwise model selection procedure was used to determine if the two-way interaction was significant in the TOTAL SHIPPING TIME models only, since the PROCESSING TIME model was assumed to be influenced by SOURCE OF SUPPLY but not CARRIERS. The two-way interaction between CARRIER and SOURCE OF SUPPLY in the TOTAL SHIPPING TIME models was determined to be negligible and was consequently removed from all models, producing simpler models with only the main effects of CARRIER and SOURCE OF SUPPLY.

1. Source of Supply Processing Time Analysis

Figure 4.1 shows the mean processing time for each source of supply. Figure 4.2 shows the medians, inter-quantile ranges and outliers of PROCESSING TIMES for each SOURCE OF SUPPLY. These boxplots are based on a natural logarithmic scale (e.g, a y-axis value of zero represents a PROCESSING TIME of one day, while a y-axis value of one represents a value of roughly 2.718). As the graph shows, SOURCES OF SUPPLY experience different average processing times and variations. For example, DDAG and USS EMORY S LAND appear to have longer average PROCESSING TIMES with larger associated variations than either DDPH or DDSP. Also, DDSP appears to have many more outliers than DDPH does. Table 4.1 is a listing of the number of requisitions processed, mean processing times and standard deviations for each of the 27 sources of supply. The data provided in Table 4.1 supports the data displayed in the Figures 4.1 and 4.2. Figure 4.3 illustrates the linear relationship between actual PROCESSING TIME observations provided by the data, and the predicted processing times based on the Poisson GLM. This is not surprising, since each SOURCE OF SUPPLY explanatory variable has its own coefficient value.

To test for significance, the 27 SOURCE OF SUPPLY labels in the dataset were permuted. The purpose of this test was to determine whether or not permuting these labels had an effect on the distribution of residual deviances. For example, Figures 4.4 and 4.5 show that permuting SOURCE OF SUPPLY LABELS did not appear to affect the residual deviance plots for DDJC, as the median, inter-quantile range, variation and outliers are roughly unchanged. However, the permutation test did appear to change the distributions for DDAG, DDPH, DDSP and USS EMORY S LAND. Thus, we conclude that all SOURCES OF SUPPLY were not equally well-fitted by the model and some were fitted better than others.

Figures 4.6 through 4.9 are the two-tailed permutation test plots which show that the observed statistics for DDAG, DDPH, DDSP and USS EMORY S LAND are well outside the range of the permutation distributions. Permutation tests resulted in *p*-values of 0.002 for DDAG, DDPH, and DDSP; and 0.010 for USS EMORY S LAND. Thus, the associated slope coefficients are in fact statistically significant for these SOURCES OF SUPPLY.

ALL DESTINATIONS

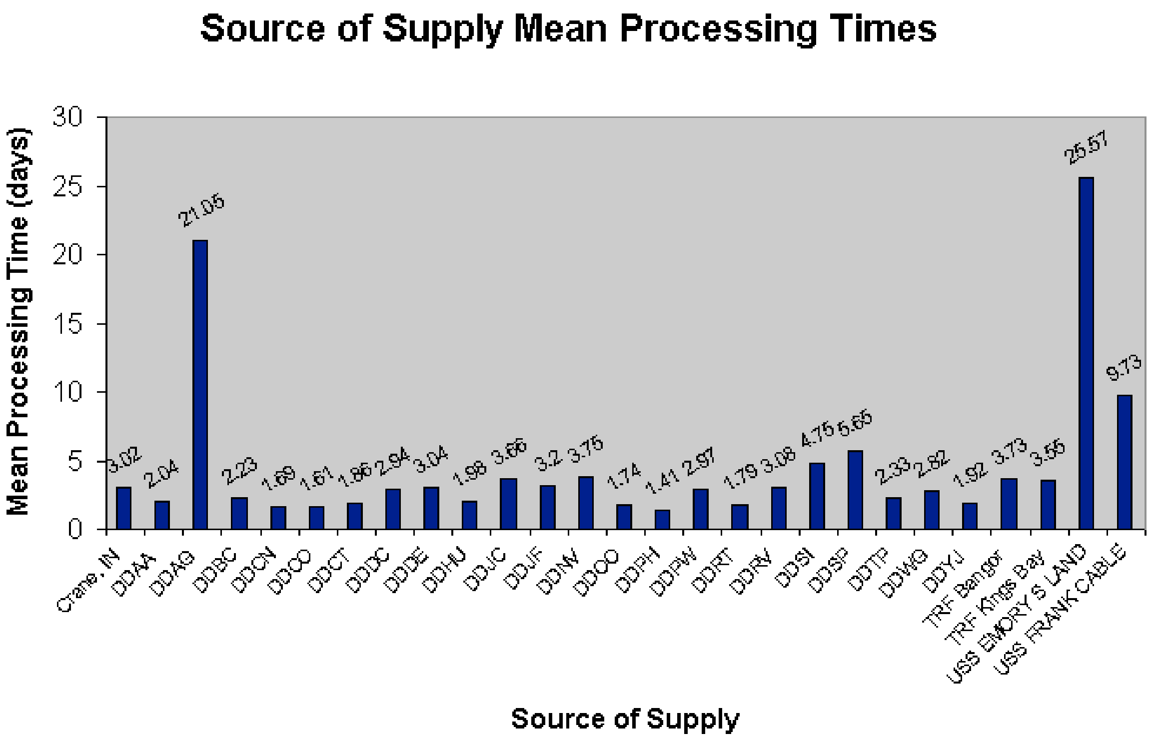


Figure 4.1. Source of Supply Mean Processing Times (for all destinations)

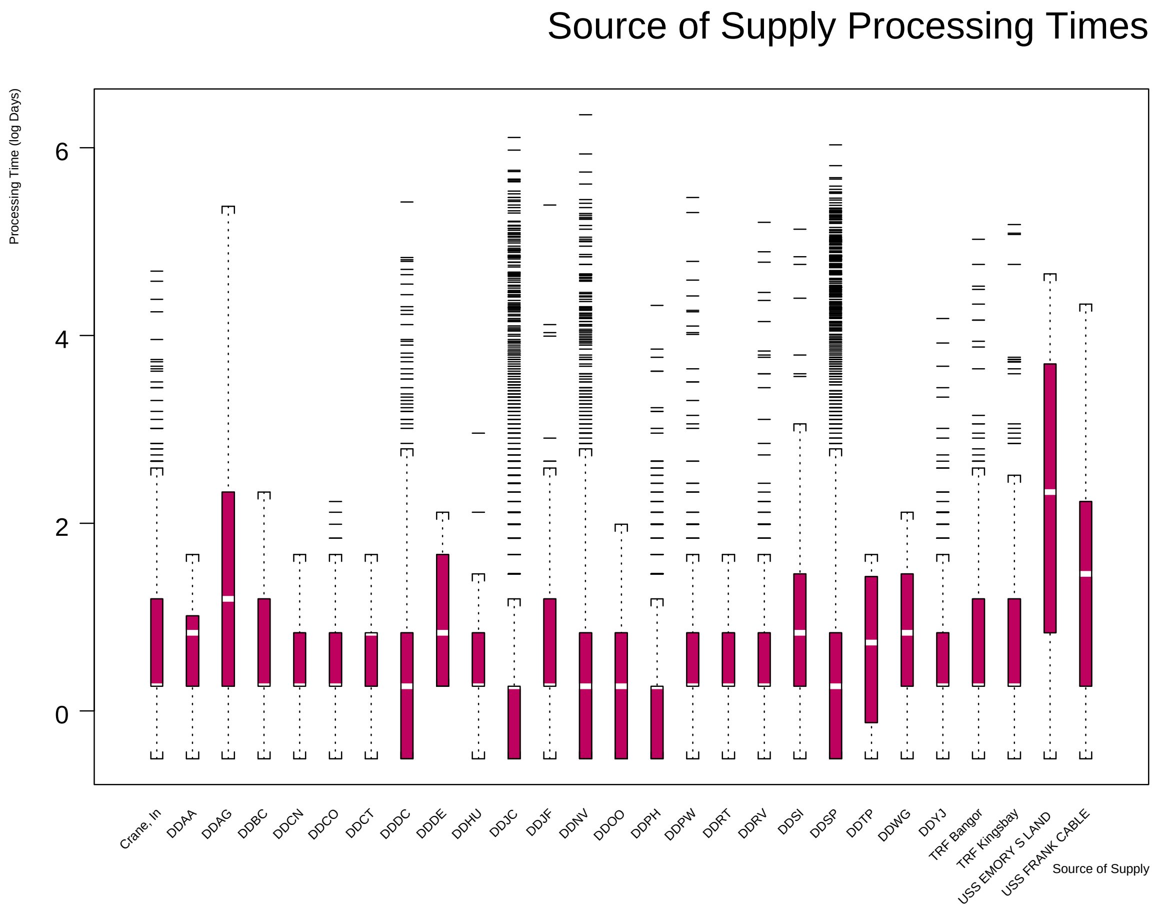


Figure 4.2. Boxplot of Source of Supply Processing Times (for all destinations)

Source of Supply	**# of Requisitions**	**Mean (days)**	**Standard Deviation (days)**
Crane, IN	1154	3.02	6.71
DDAA	8	2.04	1.46
DDAG	42	21.05	45.07
DDBC	86	2.23	2.23
DDCN	15	1.69	1.32
DDCO	218	1.61	1.37
DDCT	26	1.86	0.95
DDDC	1395	2.94	11.22
DDDE	23	3.04	2.20
DDHU	56	1.98	2.70
DDJC	7673	3.66	18.85
DDJF	320	3.20	13.39
DDNV	4204	3.75	18.87
DDOO	17	1.74	1.99
DDPH	1792	1.41	3.25
DDPW	918	2.97	12.78
DDRT	13	1.79	1.39
DDRV	573	3.08	12.55
DDSI	317	4.75	14.66
DDSP	7132	5.65	23.03
DDTP	4	2.33	2.12
DDWG	15	2.82	2.05
DDYJ	1656	1.92	2.79
TRF Bangor	525	3.73	11.84
TRF Kings Bay	814	3.55	12.20
USS EMORY S LAND	15	25.57	35.54
USS FRANK CABLE	31	9.73	17.35

Table 4.1. Number of Requisitions Processed, Mean Processing Times, and Standard Deviations for each Source of Supply (for all destinations)

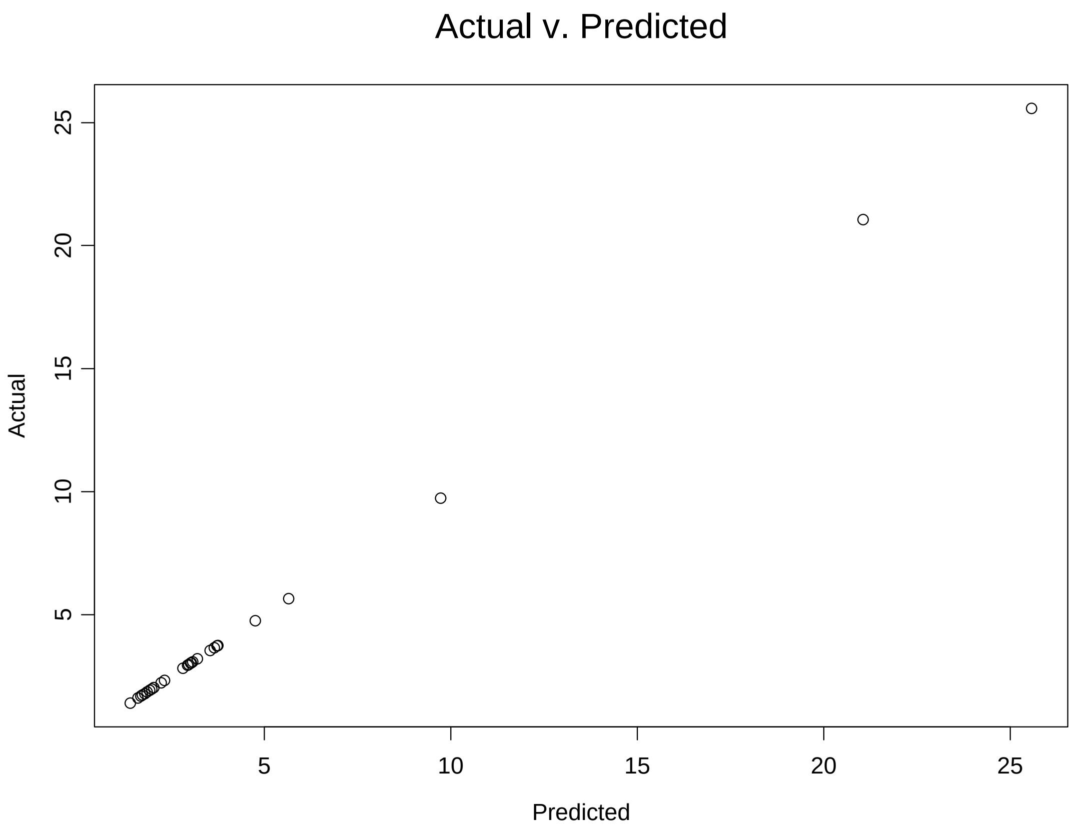


Figure 4.3. Plot of Actual v. Predicted Processing Times (all destinations)

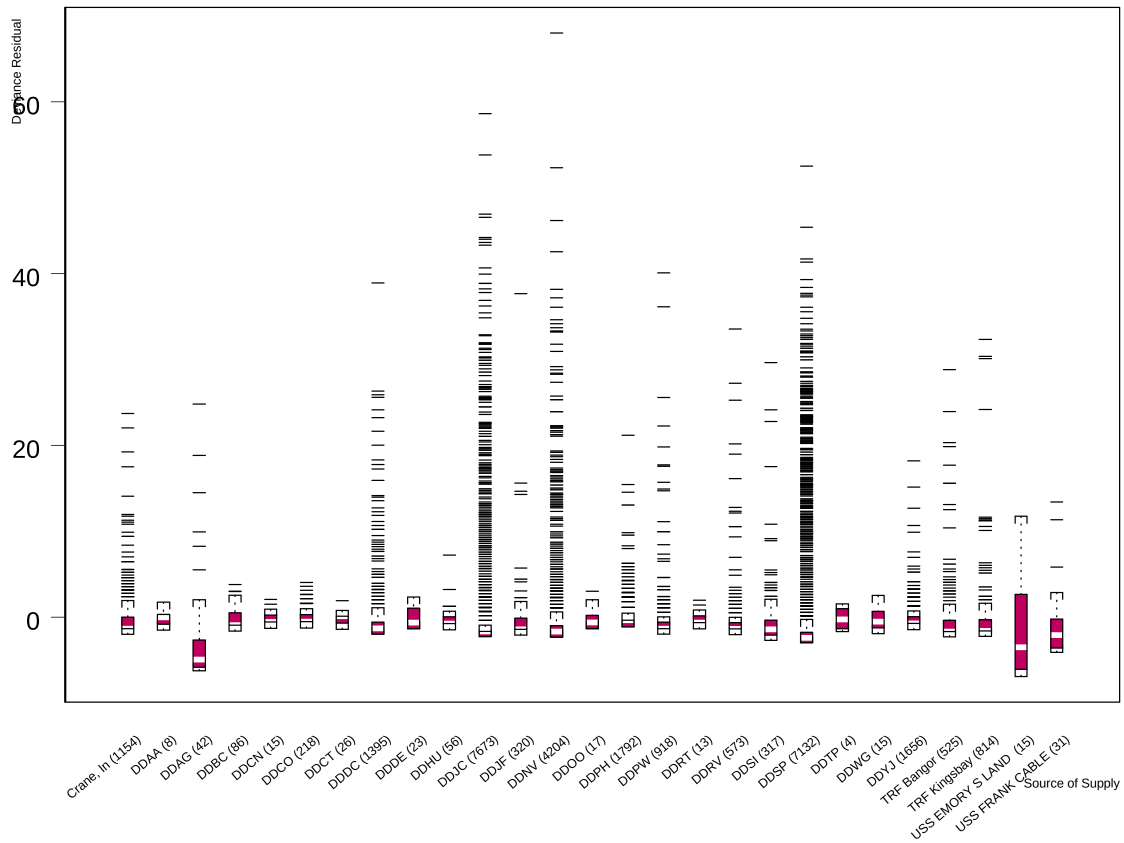


Figure 4.4. Boxplot of Source of Supply Residual Deviances (all destinations)

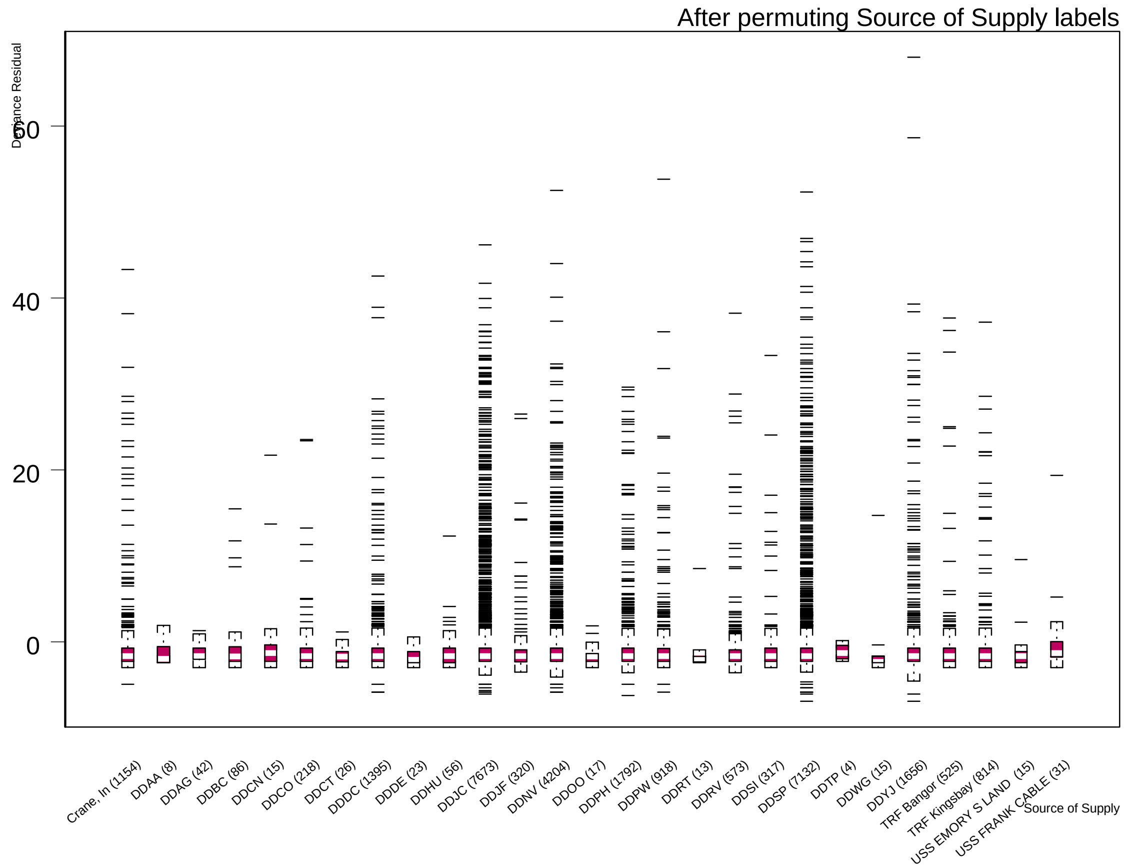


Figure 4.5. Boxplot of Source of Supply Residual Deviances After Permuting Source of Supply Labels (all destinations)

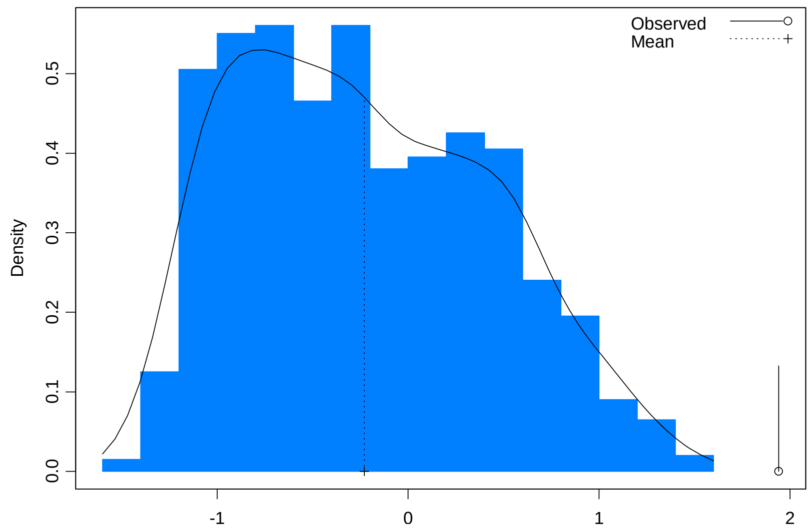


Figure 4.6. Permutation Test for Regression of Processing Time (DDAG)

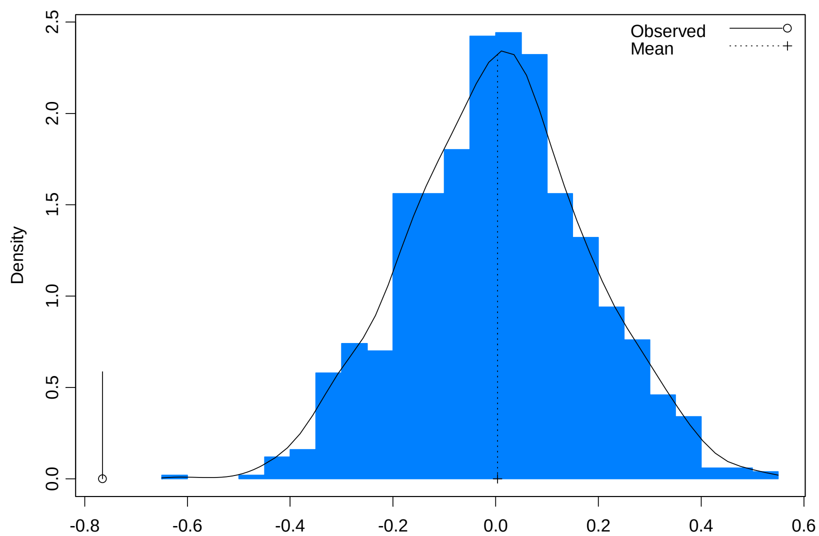


Figure 4.7. Permutation Test for Regression of Processing Time (DDPH)

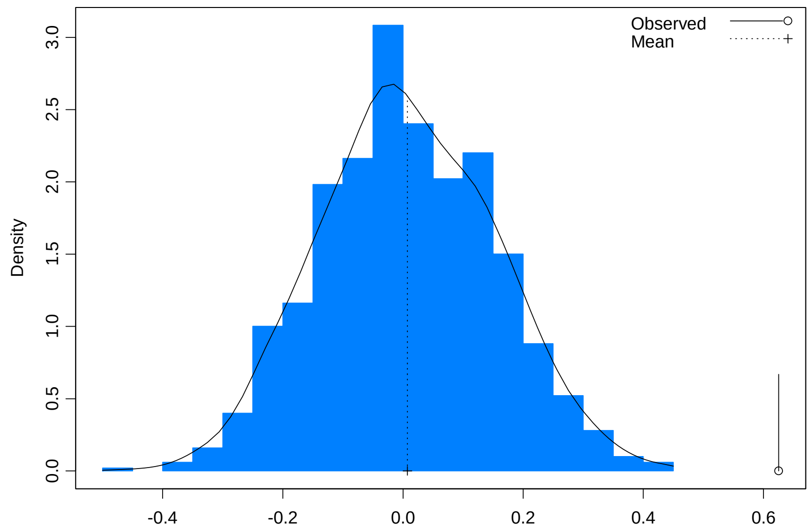


Figure 4.8. Permutation Test for Regression of Processing Time (DDSP)

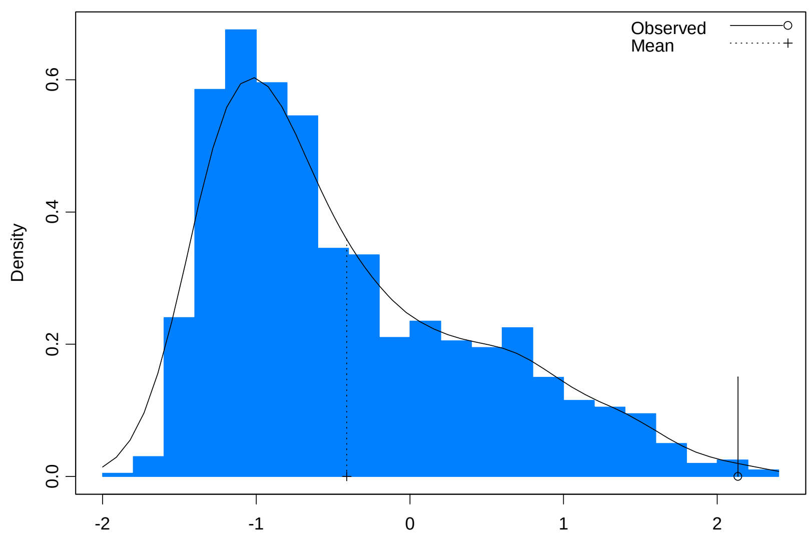


Figure 4.9. Permutation Test for Regression of Processing Time (USS EMORY S LAND)

2. Carrier Shipping Time Analysis

In a way similar to the processing time analysis, shipping time was analyzed for each of the 19 destination areas using Poisson GLMs and tested for significance by applying permutation tests. For each destination area, TOTAL SHIPPING TIME boxplots (based on a natural logarithmic scale) show the medians, fifty percentile ranges and outliers of SHIPPING TIMES for each CARRIER. Tables for each destination area provide the number of requisitions processed, and predicted SHIPPING TIME values based on SOURCE OF SUPPLY and CARRIER for each destination area. Plots for each destination area illustrate the nearly linear relationship between actual PROCESSING TIME observations provided by the data, and the predicted processing times based on the Poisson GLM (main effects only).

Significance tests were performed by permuting the SOURCE OF SUPPLY and CARRIER labels for all destination area data subsets. The purpose of these tests was to determine whether or not permuting these labels had an effect on the distribution of residual deviances. At a significance level of .05 or less, permuting SOURCE OF SUPPLY labels appeared to affect the residual deviance plots for the OKINAWA and PEARL HARBOR destination areas. Also, permuting CARRIER labels appeared to affect the residual deviance plots for GROTON, GUAM, NORFOLK, PEARL HARBOR, and SINGAPORE. Thus, we conclude that some destination area GLMs were better fit than others; and within each destination model, some SOURCES OF SUPPLY and CARRIERS were fitted better than others. Table 4.2 provides a summary of the best-fitted SOURCES OF SUPPLY and CARRIERS (along with their associated *p*-values) that resulted in the shortest shipping times for each destination area model. Included in this table is the predicted TOTAL SHIP TIME for the best-fitted SOURCE OF SUPPLY and CARRIER combinations that resulted in the shortest shipping times, where the supporting data exists. For example, although the BANGOR/BREMERTON destination area experienced the shortest shipping times with DDRT as the source of supply and NATIONAL AIR CARGO as the carrier, the dataset did not contain any requisitions that were both processed by DDRT and shipped by NATIONAL AIR CARGO.

Destination	**Source of Supply**	**SoS *p*-value**	**Carrier**	**Carrier *p*-value**	**Predicted Ship Time (days)**
Atsugi	USS FRANK CABLE	0.116	DHL	0.974	--
Bahrain	DDAA	0.172	DHL	0.072	2.00
Bangor/ Bremerton	DDRT	0.448	National Air Cargo	0.328	--
Everett	DDPH	0.382	FEDEX	0.516	2.30
Groton	DDPW	0.356	FEDEX	0.048	3.40
Guam	DDYJ	0.062	DHL	0.002	4.20
Hong Kong	DDYJ	0.328	DHL	0.056	4.20
Kings Bay	DDSP	0.118	FEDEX	0.466	2.80
Mayport	DDCO	0.544	DHL	0.978	--
Mildenhall	Crane, IN	0.592	DHL	0.18	4.10
Norfolk	DDBC	0.37	FEDEX	0.002	2.00
Okinawa	Crane, IN	0.04	DHL	0.34	2.60
Pearl Harbor	TRF Bangor	0.05	LANDSTAR/ Military Air Cargo	0.016	2.20
Rota	Crane, IN	0.136	DHL	0.538	4.60
San Diego	Crane, IN	0.338	DHL	0.638	--
Sasebo	DDPH	0.094	FEDEX	0.18	5.10
Sigonella	Crane, IN	0.438	DHL	0.686	6.40
Singapore	DDYJ	0.13	DHL	0.002	3.60
Yokosuka	DDPH USS FRANK CABLE	0.156	DHL	0.41	4.20 2.00

Table 4.2. Predicted Shipping Times for the Best-Fitted SOURCES OF SUPPLY and CARRIERS Resulting in the Shortest Shipping Times, by IPG-1 Requisition Destination Areas

The Friedman nonparametric test was performed for the GUAM destination area, which had a large number of observations. In this dataset, there were multiple SOURCE OF SUPPLY/CARRIER combinations that were missing TOTAL SHIPPING TIME data; in particular, a significant number of values for UPS were missing. Therefore, in order to analyze this dataset, a two-way matrix was constructed by including the major carriers DHL and FEDEX (UPS was not included due to missing data), and all source of supply locations which utilized both DHL and FEDEX. In this way, a rank test was conducted for the two carriers while blocking across source of supply, resulting in a *p*-value of 0.0027. The results indicate that DHL performed significantly better than FEDEX for IPG-1 requisitions to GUAM (where data was available). The Friedman test results are supported by the GUAM shipping time data.

Appendices B through T contain shipping time boxplots, tables with number of requisitions according to source of supply and carrier, plots of actual shipping times versus predicted shipping times, and tables with predicted shipping time values for each of the 19 IPG-1 requisition destination areas of interest in this study. Also included in these appendices are the permutation tests of residual deviances for the destination area models in which SOURCE OF SUPPLY and CARRIER label permutation effects were significant (GROTON, GUAM, NORFOLK, OKINAWA, PEARL HARBOR, SINGAPORE).

.

V. SUMMARY, LIMITATIONS AND RECOMMENDATIONS

The purpose of this study was to examine whether or not source of supply and carrier had an effect on processing and shipping times for IPG-1 requisitions to primary overseas destinations of U.S. Navy units operating in the Fifth, Sixth, and Seventh Fleet Areas of Operation (AORs) and major Fleet concentration areas within the United States. In the course of the study, the following questions were explored:

- Is there statistical evidence to indicate that source of supply affects processing times of IPG-1 requisitions to destinations within the Fifth, Sixth, and Seventh Fleet AORs and continental U.S.?
- Is there statistical evidence to indicate that source of supply, carrier, and/or the interaction of these two variables, affect shipping times of IPG-1 requisitions to destinations within the Fifth, Sixth, and Seventh Fleet AORs and continental U.S.?
- What carrier, source of supply, and combinations of these two factors have the smallest mean processing and shipping times for the various destinations?

The IPG-1 requisition data used in this study was provided by the Priority Material Office and covered the period February 2005 to February 2008. The destination areas included in this study were: Atsugi, Bahrain, Guam, Hong Kong, Mildenhall (UK), Okinawa, Rota, Sasebo, Sigonella, Singapore, Yokosuka, Bangor/Bremerton, Everett, Groton, Kings Bay, Mayport, Norfolk, Pearl Harbor, and San Diego. Destinations were analyzed separately for shipping time analysis, but were not separated for source of supply processing time analysis.

This study was limited to primary sources of supply for IPG-1 requisitions. For the purpose of this study, a primary source of supply was defined as a single DoD or Navy distribution center, or a group of DoD and Navy distribution activities within a single geographic location that shipped at least 200 IPG-1 requisitions during the three-year period of the historical requisition data, or was of special interest to PMO. Federal

Express® (FedEx®), DHL Worldwide Express® (DHL®), United Parcel Service, Inc.® (UPS®), Air Mobility Command (AMC) and commercial freight forwarders were the carriers included in the analysis. Due to the scarce amount of data available in some cases, not all carriers were included in the analysis. Specifically, AMC was not included in any of the 19 shipping time analyses since it did not make more than ten deliveries to any one destination location.

Quantile-Normal plots of each model's residuals were used to determine the suitability of the ordinary linear model. Because the errors were not normally distributed, the ordinary linear model was rejected in favor of the Poisson GLMs. Nonparametric statistical analysis was performed to support the GLM analysis, using permutation resampling and Friedman tests. Permutation testing indicated that not all carriers were equally well-fit by their respective models, and Friedman tests indicated that mean shipping times between carriers were significantly different in the model on which they were performed.

Limitations of this study were primarily driven by the amount of data that was available. Despite the initial dataset size of over 95,000 processing entries, the useable dataset was reduced by approximately ten percent due to missing entries, or incorrect entries that resulted in negative processing or shipping times. The effects of this became even more pronounced upon dividing the data into 19 subsets in order to analyze shipping times for different destination areas. Additionally, analysis of the data revealed that certain carriers were used more frequently than others to deliver requisitioned items from sources of supply to a destination location. Despite limitations, the available data did show that in some cases carriers with better shipping times were under-utilized. For example, despite shorter shipping times for DHL, there were several sources of supply that used FEDEX more frequently when delivering items to Guam.

The purpose of this study was to investigate the historical effects of source of supply selection on processing times, and on source of supply and carrier selection on shipping times to destination areas of interest. It did not attempt to provide an in-depth review of the operations of sources of supply and carriers, or uncover the reasons for processing and shipping time differences between them.

One recommended area for further study is optimization model development, upon collecting source of supply and carrier capacity information. Using this information with the results of this study, it may be possible to determine an optimal solution based on given source of supply and carrier constraints. Periodic review of statistical data and model assumptions would help to account for changes to source of supply and carrier operational practices, and consequently to model constraints.

Another possible area for further study is determining the effects of weather phenomena on shipping times. Integrating weather information into a statistics-based model may help to refine source of supply selection on a real-time basis, particularly if there are multiple sources of supply that provide nearly equal shipping times. One more possible area for further study is a statistical analysis on acquisition times of contracted companies, when requisitioned items that are unavailable in the Navy supply inventory must be manufactured.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. QUANTILE-NORMAL PLOTS OF OLS LINEAR MODEL RESIDUALS

Figure A.1. Processing Times (all destinations)

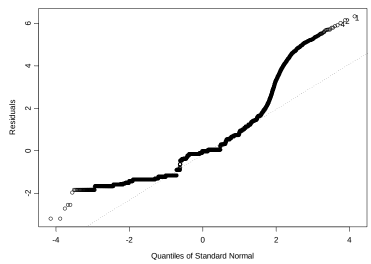
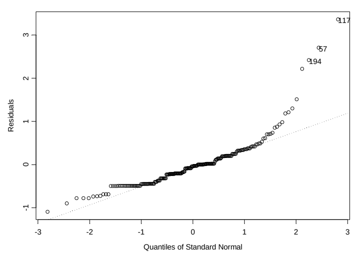
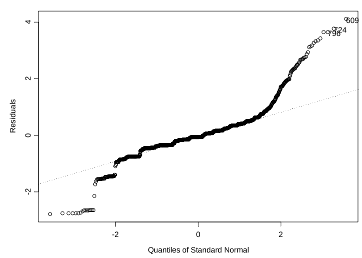


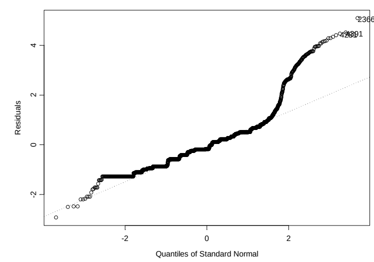
Figure A.2. Total Shipping Times



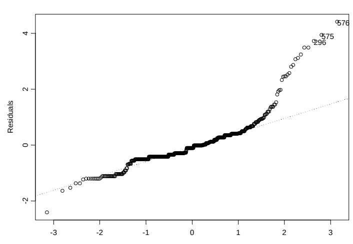
Atsugi



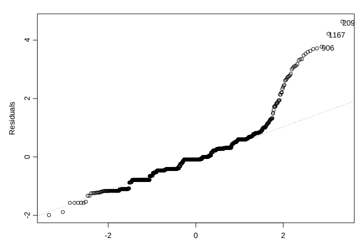
Bahrain



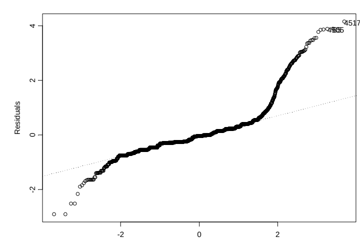
Bangor/Bremerton



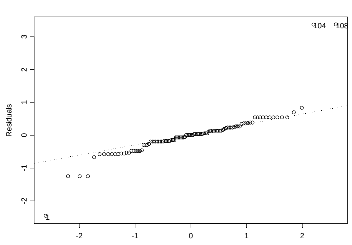
Everett



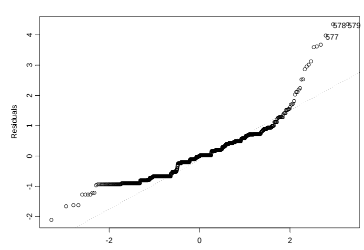
Groton



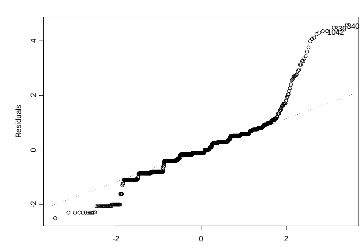
Guam



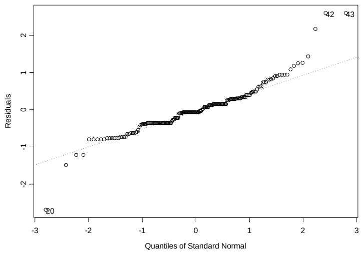
Hong Kong



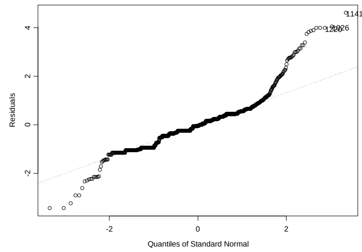
Kings Bay



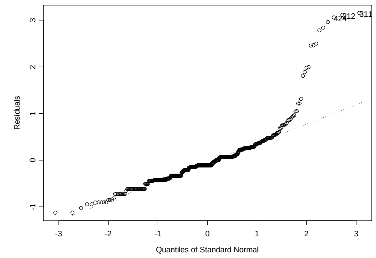
Mayport



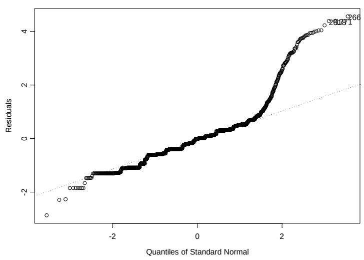
Mildenhall



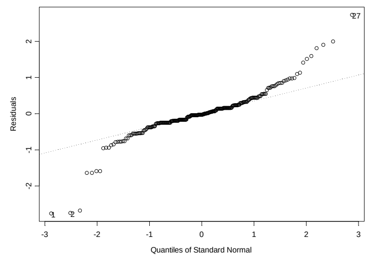
Norfolk



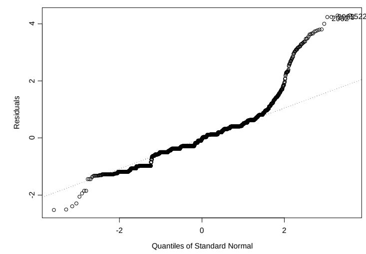
Okinawa



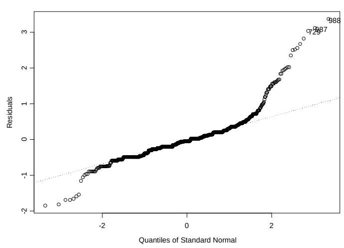
Pearl Harbor



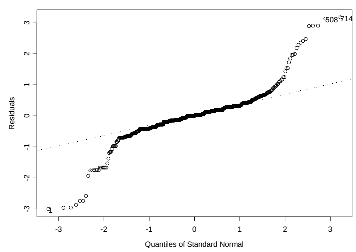
Rota



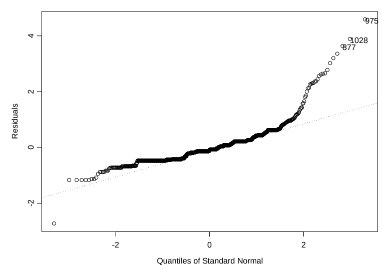
San Diego



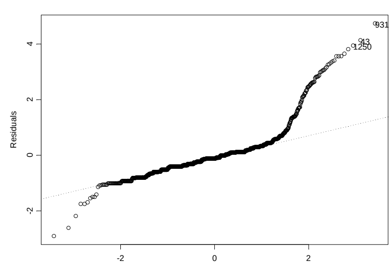
Sasebo



Sigonella



Singapore



Yokosuka

APPENDIX B. ATSUGI ANALYSIS RESULTS

Figure B.1. Boxplot of primary Carrier Shipping Times (ATSUGI)

Source \ Carrier	DHL	FEDEX
Crane, In	1	11
DDCO	0	1
DDDC	2	23
DDJC	12	57
DDJF	1	0
DDNV	0	24
DDPH	0	13
DDPW	3	6
DDRV	2	0
DDSI	0	1
DDSP	20	18
DDYJ	0	1
TRF Bangor	1	1
TRF Kingsbay	0	1
USS FRANK CABLE	0	1

Table B.1. Number of Source of Supply/Carrier Requisitions in Dataset (ATSUGI)

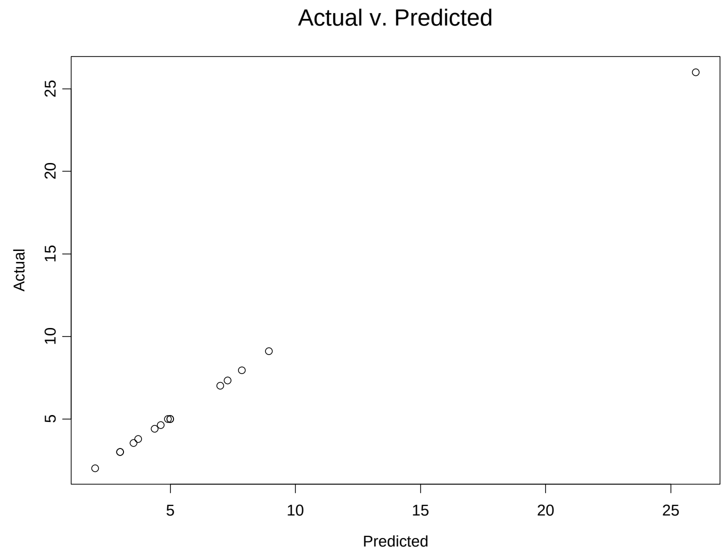


Figure B.2. Plot of Actual v. Predicted Shipping Times (ATSUGI)

Source \ Carrier	DHL	FEDEX
Crane, In	5.2	7.5
DDCO	NA	3.0
DDDC	3.1	4.5
DDJC	5.8	8.4
DDJF	7.0	NA
DDNV	NA	4.6
DDPH	NA	3.5
DDPW	2.9	4.2
DDRV	3.0	NA
DDSI	NA	26.0
DDSP	7.5	10.9
DDYJ	NA	5.0
TRF Bangor	4.1	5.9
TRF Kingsbay	NA	5.0
USS FRANK CABLE	NA	2.0

Table B.2. Predicted Shipping Time Values (ATSUGI)

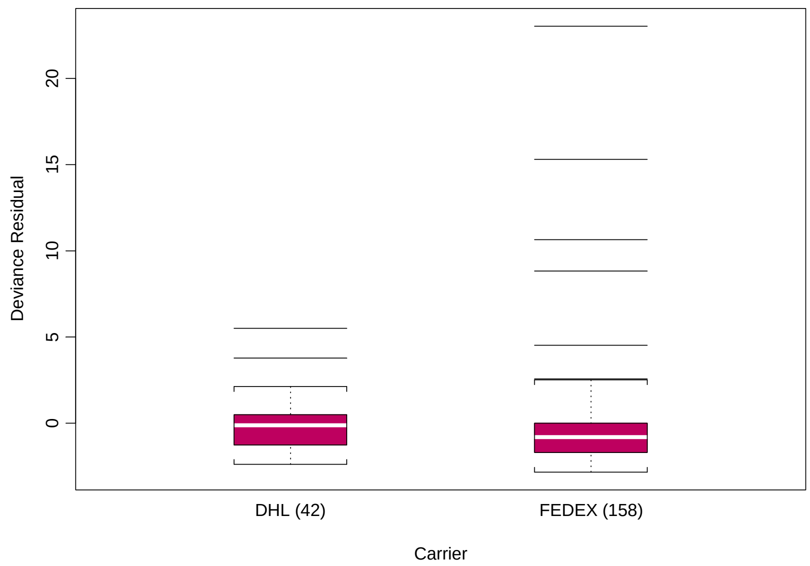


Figure B.3. Boxplot of Carrier Residual Deviances (ATSUGI)

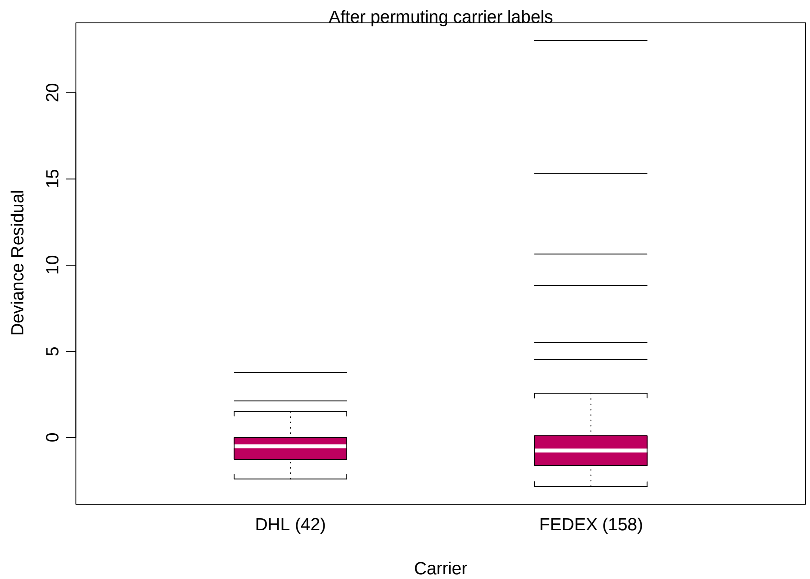


Figure B.4. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (ATSUGI)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. BAHRAIN ANALYSIS RESULTS

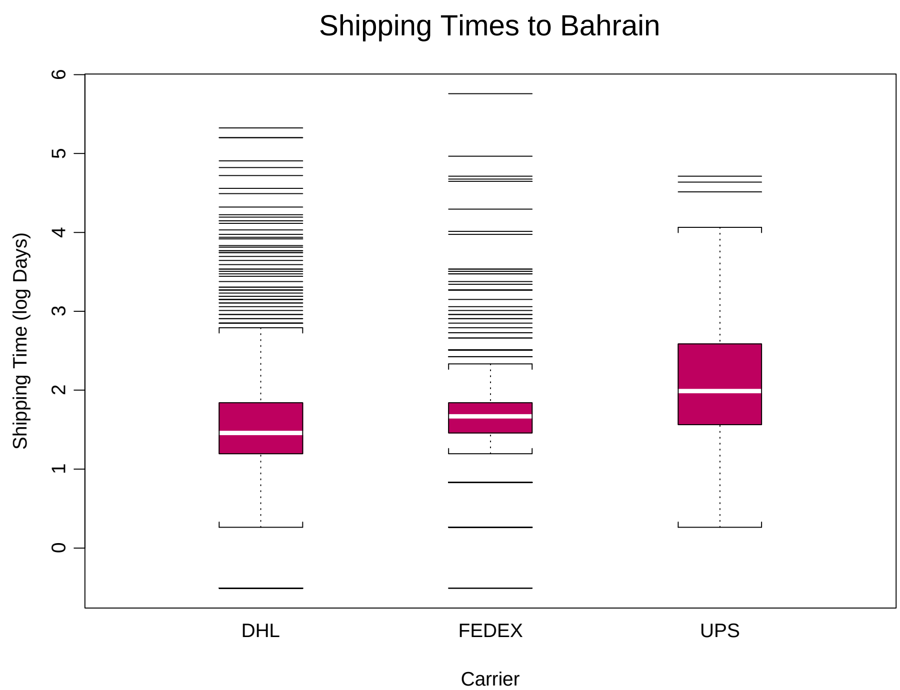


Figure C.1. Boxplot of primary Carrier Shipping Times (BAHRAIN)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	85	63	1
DDAA	1	0	0
DDCN	1	0	0
DDCO	8	2	0
DDCT	2	18	0
DDDC	41	129	0
DDDE	3	2	1
DDHU	2	2	0
DDJC	445	59	4
DDJF	7	52	0
DDNV	296	208	14
DDOO	0	1	0
DDPH	24	60	0
DDPW	17	1	0
DDRT	0	3	0
DDRV	56	9	0
DDSI	8	31	0
DDSP	746	266	27
DDWG	0	1	1
DDYJ	161	5	0
TRF Bangor	0	7	0
TRF Kings Bay	0	16	0
USS EMORY S LAND	0	2	0

Table C.1. Number of Source of Supply/Carrier Requisitions in Dataset (BAHRAIN)

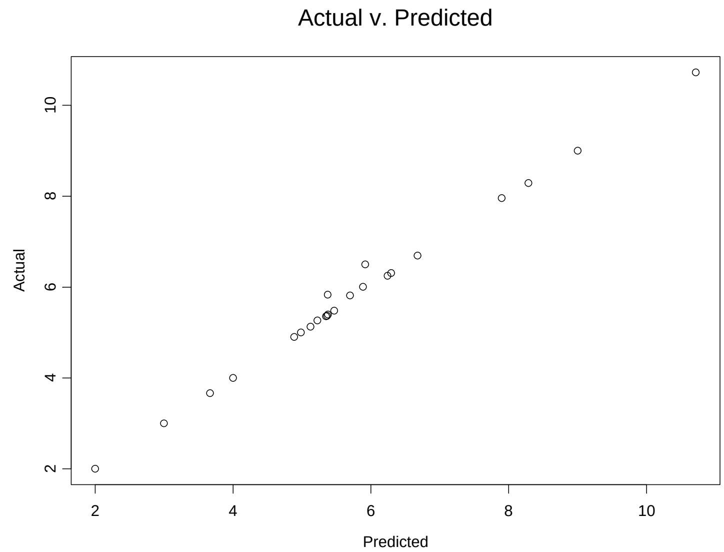


Figure C.2. Plot of Actual v. Predicted Shipping Times (BAHRAIN)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	4.9	5.7	13.7
DDAA	2.0	NA	NA
DDCN	3.0	NA	NA
DDCO	4.7	5.5	NA
DDCT	5.4	6.3	NA
DDDC	5.6	6.5	NA
DDDE	4.3	5.0	12.1
DDHU	4.6	5.4	NA
DDJC	7.7	9.0	21.7
DDJF	4.7	5.4	NA
DDNV	5.2	6.1	14.6
DDOO	NA	4.0	NA
DDPH	4.8	5.6	NA
DDPW	10.6	12.4	NA
DDRT	NA	3.7	NA
DDRV	5.4	6.3	NA
DDSI	5.9	6.9	NA
DDSP	5.5	6.4	15.5
DDWG	NA	3.8	9.2
DDYJ	5.3	6.2	NA
TRF Bangor	NA	8.3	NA
TRF Kings Bay	NA	5.1	NA
USS EMORY S LAND	NA	9.0	NA

Table C.2. Predicted Shipping Time Values (BAHRAIN)

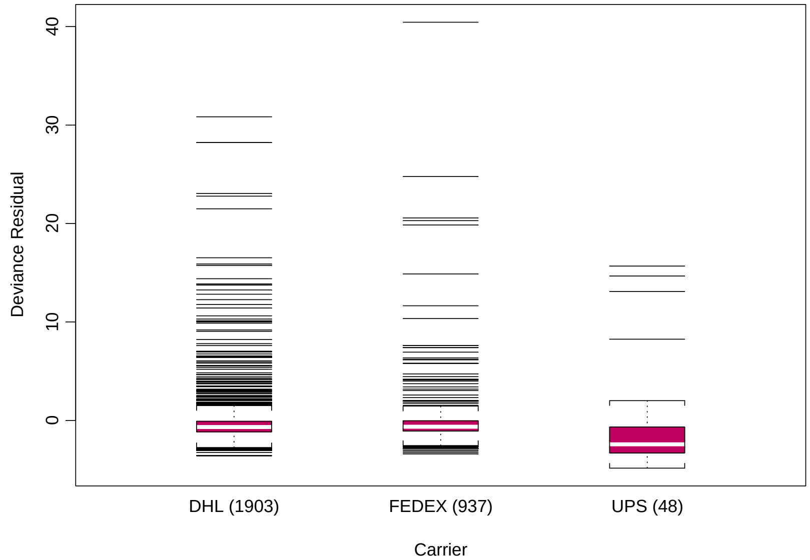


Figure C.3. Boxplot of Carrier Residual Deviances (BAHRAIN)

APPENDIX D. BANGOR/BREMERTON ANALYSIS RESULTS

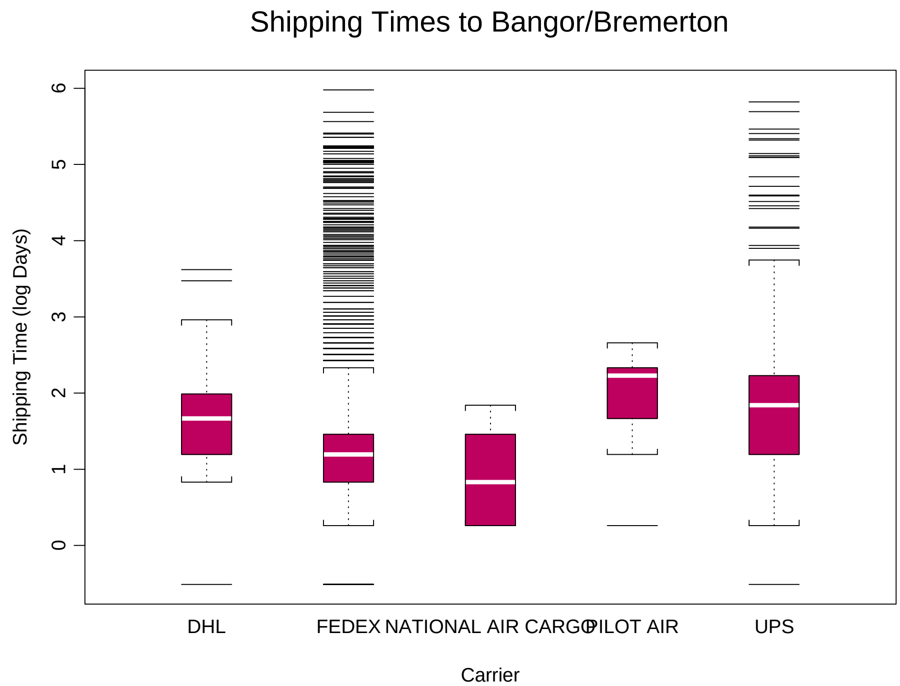


Figure D.1. Boxplot of primary Carrier Shipping Times (BANGOR/BREMERTON)

Source \ Carrier	DHL	FEDEX	NATIONAL AIR CARGO	PILOT AIR	UPS
Crane,In	0	13	0	0	0
DDAA	0	1	0	0	0
DDAG	0	9	0	1	3
DDBC	0	10	0	0	0
DDCN	0	4	0	0	0
DDCO	0	51	0	0	1
DDDC	0	102	0	0	1
DDDE	0	0	0	0	2
DDHU	0	13	0	0	0
DDJC	0	1279	17	2	101
DDJF	0	23	0	0	3
DDNV	2	289	0	0	22
DDOO	0	7	0	0	0
DDPH	36	161	0	0	6
DDPW	0	314	0	0	2
DDRT	0	1	0	0	0
DDRV	2	113	0	0	0
DDSI	1	23	0	0	0
DDSP	2	1007	0	0	66
DDTP	0	0	0	0	2
DDWG	0	0	0	0	1
DDYJ	28	84	0	0	6
TRF Bangor	0	8	0	0	2
TRF Kingsbay	1	544	0	11	54
USS EMORY S LAND	1	2	0	0	0
USS FRANK CABLE	4	1	0	0	0

Table D.1. Number of Source of Supply/Carrier Requisitions in Dataset (BANGOR/BREMERTON)

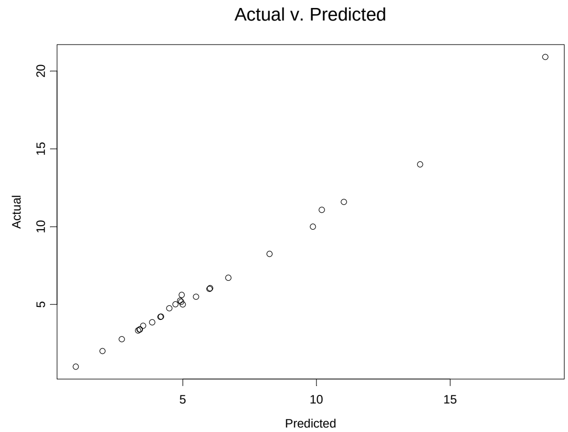


Figure D.2. Plot of Actual v. Predicted Shipping Times (BANGOR/BREMERTON)

Source \ Carrier	DHL	FEDEX	NATIONAL AIR CARGO	PILOT AIR	UPS
Crane,IN	NA	3.4	NA	NA	NA
DDAA	NA	5.0	NA	NA	NA
DDAG	NA	3.7	NA	6.8	11.1
DDBC	NA	3.4	NA	NA	NA
DDCN	NA	8.3	NA	NA	NA
DDCO	NA	2.7	NA	NA	8.1
DDDC	NA	4.1	NA	NA	12.5
DDDE	NA	NA	NA	NA	6.0
DDHU	NA	3.3	NA	NA	NA
DDJC	NA	4.4	2.6	8.1	13.3
DDJF	NA	9.0	NA	NA	27.1
DDNV	5.8	4.2	NA	NA	12.6
DDOO	NA	3.9	NA	NA	NA
DDPH	4.5	3.2	NA	NA	9.7
DDPW	NA	4.2	NA	NA	12.6
DDRT	NA	1.0	NA	NA	NA
DDRV	9.4	6.7	NA	NA	NA
DDSI	8.3	5.9	NA	NA	NA
DDSP	14.5	10.3	NA	NA	31.1
DDTP	NA	NA	NA	NA	5.5
DDWG	NA	NA	NA	NA	2.0
DDYJ	6.1	4.3	NA	NA	13.0
TRF Bangor	NA	14.9	NA	NA	45.0
TRF Kings Bay	6.2	4.4	NA	8.1	13.3
USS EMORY S LAND	12.4	8.8	NA	NA	NA
USS FRANK CABLE	14.9	10.6	NA	NA	NA

Table D.2. Predicted Shipping Time Values (BANGOR/BREMERTON)

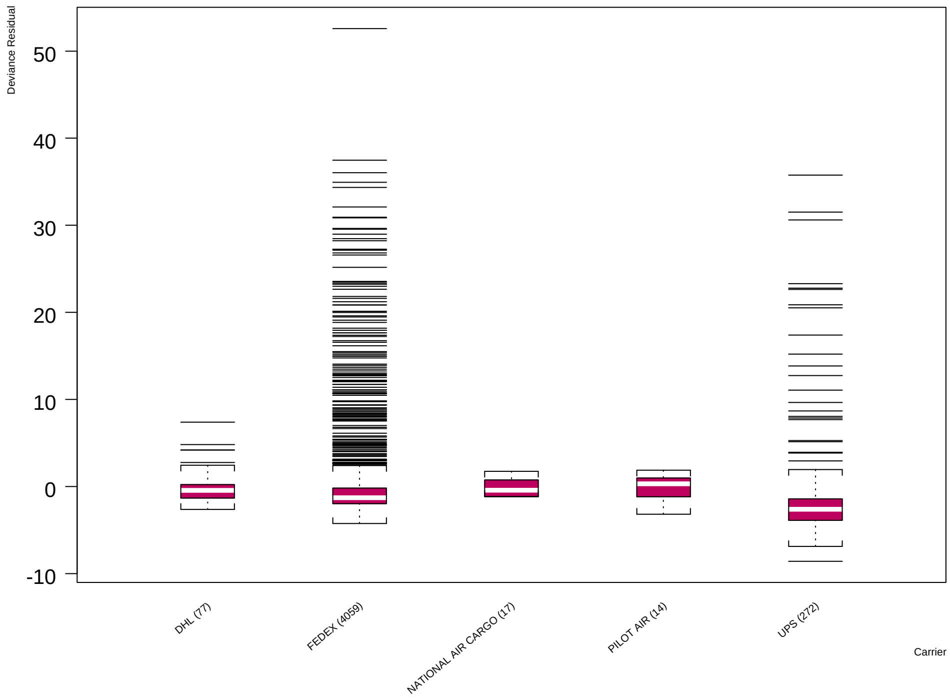


Figure D.3. Boxplot of Carrier Residual Deviances (BANGOR/BREMERTON)

APPENDIX E. EVERETT ANALYSIS RESULTS

Figure E.1. Boxplot of primary Carrier Shipping Times (EVERETT)

Source \ Carrier	FEDEX	UPS
Crane,IN	40	1
DDBC	4	1
DDCO	7	0
DDCT	1	0
DDDC	52	0
DDDE	0	1
DDJC	192	11
DDJF	6	1
DDNV	78	12
DDPH	12	0
DDPW	29	0
DDRT	2	0
DDRV	5	0
DDSP	112	3
DDTP	1	0
DDYJ	19	1
TRF Bangor	1	0
TRF Kings Bay	3	0

Table E.1. Number of Source of Supply/Carrier Requisitions in Dataset (EVERETT)

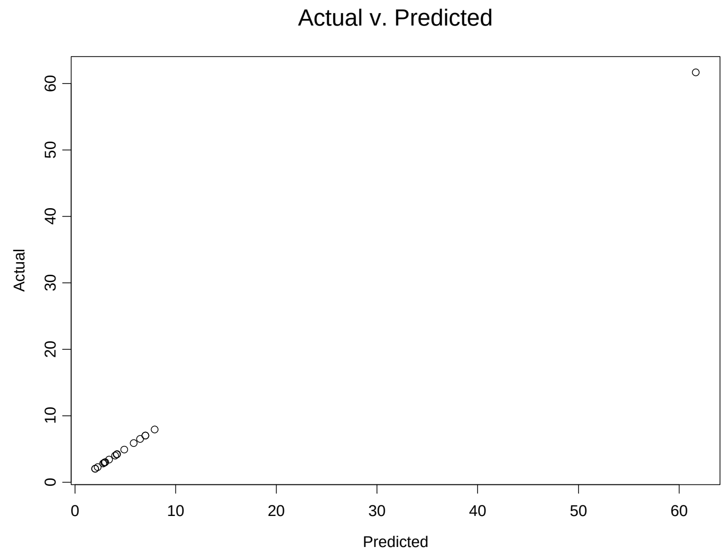


Figure E.2. Plot of Actual v. Predicted Shipping Times (EVERETT)

Source \ Carrier	FEDEX	UPS
Crane,IN	4.9	6.3
DDBC	3.2	4.2
DDCO	3.0	NA
DDCT	2.0	NA
DDDC	2.9	NA
DDDE	NA	7.0
DDJC	6.4	8.2
DDJF	5.6	7.3
DDNV	4.0	5.2
DDPH	2.3	NA
DDPW	2.9	NA
DDRT	4.0	NA
DDRV	2.8	NA
DDSP	7.9	10.2
DDTP	7.0	NA
DDYJ	4.1	5.3
TRF Bangor	2.0	NA
TRF Kings Bay	61.7	NA

Table E.2. Predicted Shipping Time Values (EVERETT)

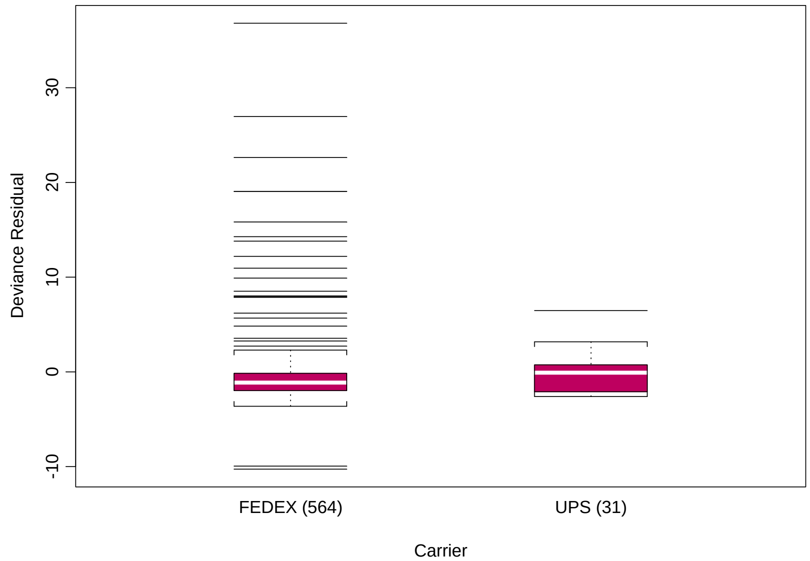


Figure E.3. Boxplot of Carrier Residual Deviances (EVERETT)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX F. GROTON ANALYSIS RESULTS

Figure F.1. Boxplot of Primary Carrier Shipping Times (GROTON)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	0	12	0
DDAA	0	1	0
DDBC	0	1	1
DDCO	0	12	0
DDDC	0	41	0
DDJC	0	156	1
DDJF	0	14	0
DDNV	2	278	10
DDPH	15	53	0
DDPW	0	57	0
DDRV	0	28	0
DDSI	0	5	0
DDSP	2	406	74
DDYJ	0	19	0
TRF Bangor	0	17	0
TRF Kings Bay	0	32	0
USS EMORY S LAND	1	0	0
USS FRANK CABLE	2	0	0

Table F.1. Number of Source of Supply/Carrier Requisitions in Dataset (GROTON)

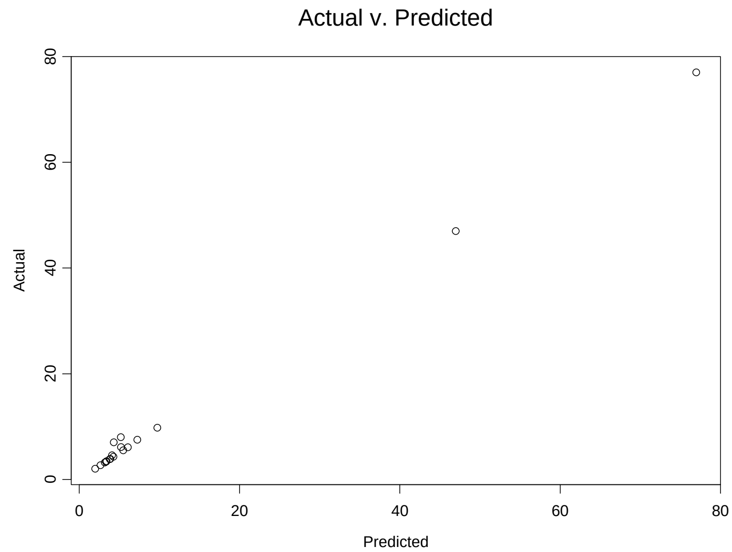


Figure F.2. Plot of Actual v. Predicted Shipping Times (GROTON)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	NA	6.1	NA
DDAA	NA	2.0	NA
DDBC	NA	1.5	12.5
DDCO	NA	2.7	NA
DDDC	NA	9.8	NA
DDJC	NA	7.2	60.1
DDJF	NA	4.3	NA
DDNV	13.3	4.8	40.3
DDPH	9.1	3.3	NA
DDPW	NA	3.4	NA
DDRV	NA	5.5	NA
DDSI	NA	3.2	NA
DDSP	10.3	3.7	31.3
DDYJ	NA	3.4	NA
TRF Bangor	NA	3.8	NA
TRF Kings Bay	NA	3.9	NA
USS EMORY S LAND	77.0	NA	NA
USS FRANK CABLE	47.0	NA	NA

Table F.2. Predicted Shipping Time Values (GROTON)

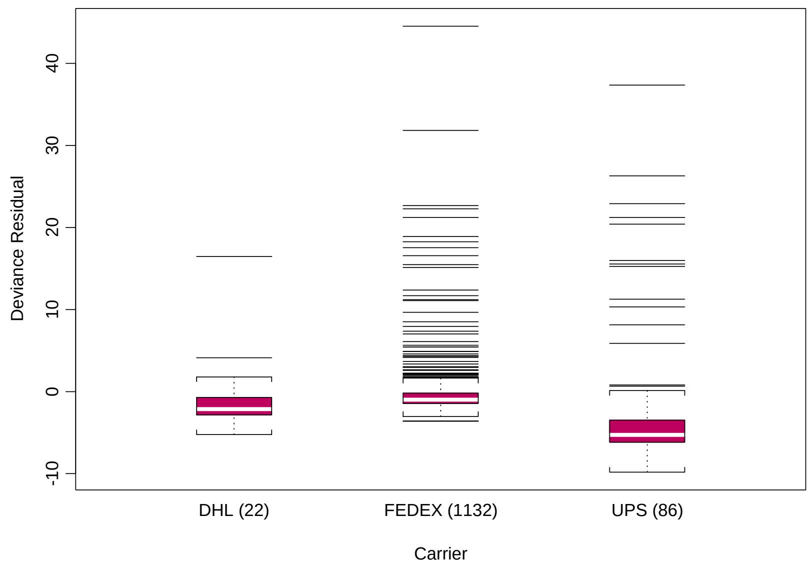


Figure F.3. Boxplot of Carrier Residual Deviances (GROTON)

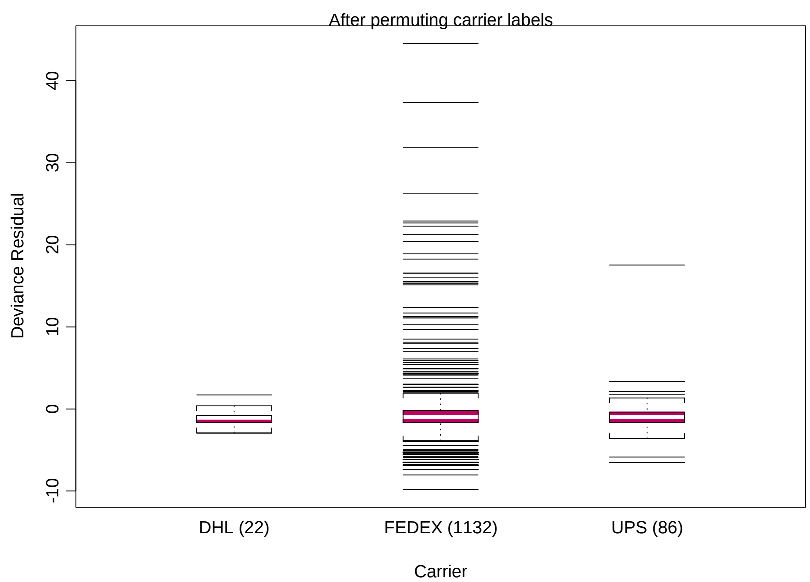


Figure F.4. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (GROTON)

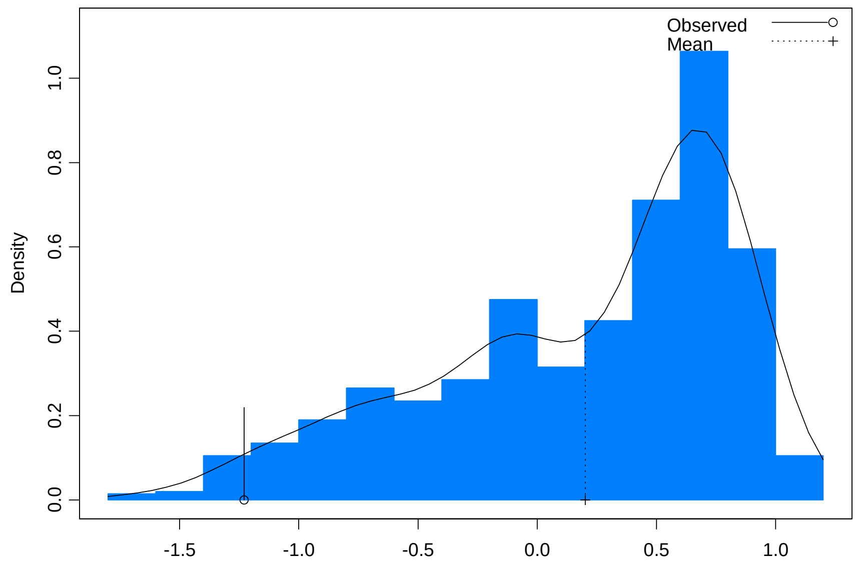


Figure F.5. Permutation Test for Regression of Shipping Time (FEDEX)

APPENDIX G. GUAM ANALYSIS RESULTS

Figure G.1. Boxplot of Primary Carrier Shipping Times (GUAM)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	2	51	0
DDAA	0	1	0
DDAG	3	6	3
DDBC	1	16	0
DDCN	1	1	2
DDCO	0	45	1
DDDC	1	179	2
DDDE	1	0	0
DDHU	0	10	0
DDJC	237	1137	1
DDJF	3	16	0
DDNV	77	215	48
DDOO	0	2	0
DDPH	133	563	7
DDPW	29	113	0
DDRV	1	69	0
DDSI	6	22	1
DDSP	195	583	17
DDWG	0	3	0
DDYJ	593	14	5
TRF Bangor	3	62	2
TRF Kings Bay	0	39	0
USS EMORY S LAND	1	2	0
USS FRANK CABLE	1	6	0

Table G.1. Number of Source of Supply/Carrier Requisitions in Dataset (GUAM)

Actual v. Predicted

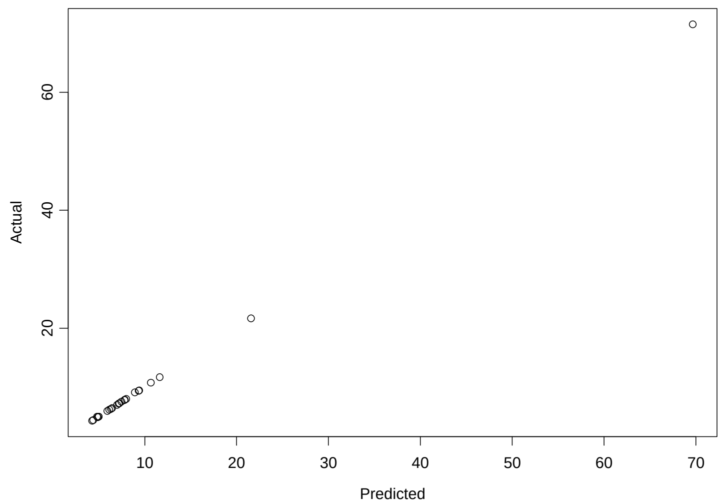


Figure G.2. Plot of Actual v. Predicted Shipping Times (GUAM)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	6.5	7.9	NA
DDAA	NA	5.0	NA
DDAG	54.5	65.7	100.1
DDBC	4.2	5.1	NA
DDCN	3.4	4.1	6.2
DDCO	NA	5.9	9.0
DDDC	5.1	6.1	9.3
DDDE	8.0	NA	NA
DDHU	NA	4.9	NA
DDJC	6.2	7.5	11.4
DDJF	8.0	9.7	NA
DDNV	7.3	8.8	13.4
DDOO	NA	7.0	NA
DDPH	3.8	4.6	6.9
DDPW	6.2	7.5	NA
DDRV	7.8	9.4	NA
DDSI	6.4	7.6	11.7
DDSP	9.2	11.1	16.9
DDWG	NA	6.3	NA
DDYJ	4.2	5.1	7.8
TRF Bangor	9.6	11.6	17.7
TRF Kings Bay	NA	6.5	NA
USS EMORY S LAND	19.1	23.0	NA
USS FRANK CABLE	6.7	8.1	NA

Table G.2. Predicted Shipping Time Values (GUAM)

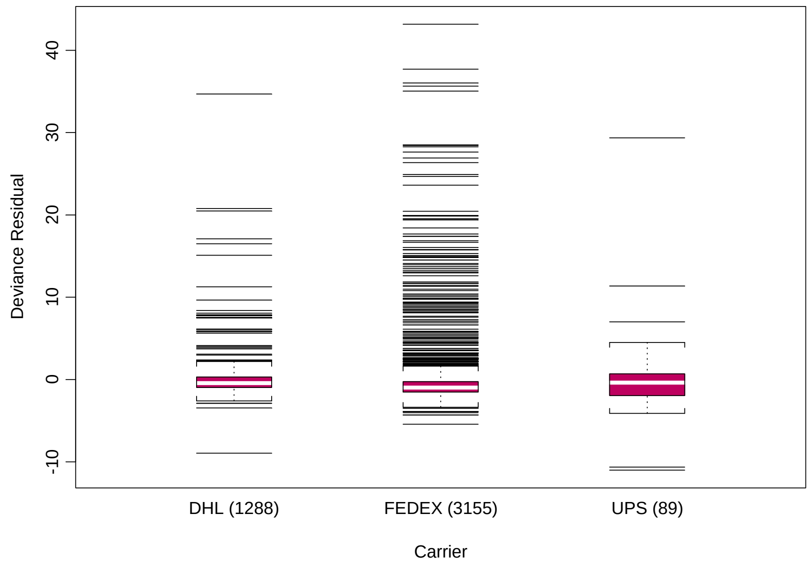


Figure G.3. Boxplot of Carrier Residual Deviances (GUAM)

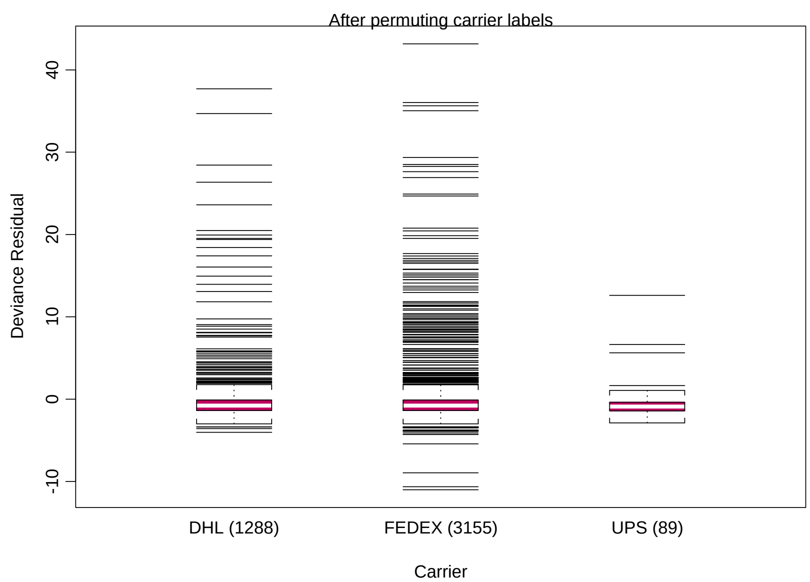


Figure G.4. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (GUAM)

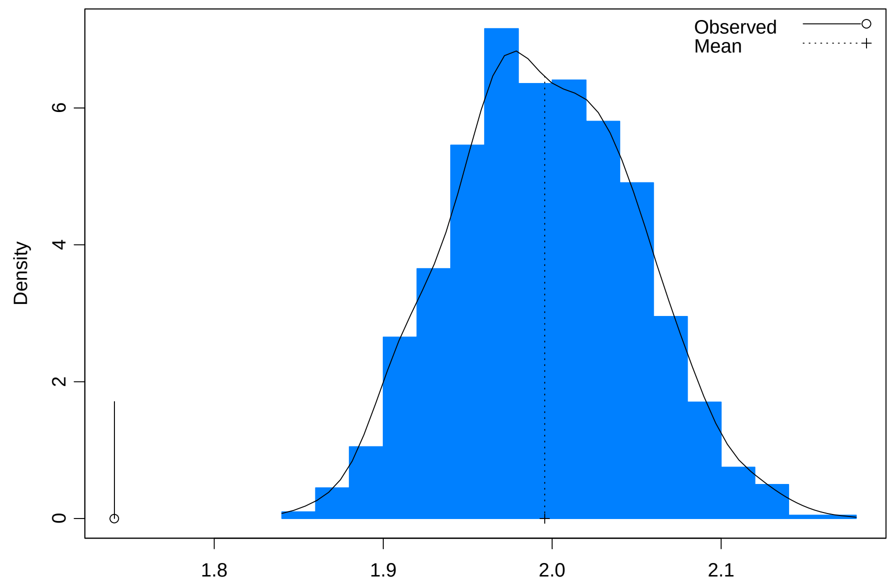


Figure G.5. Permutation Test for Regression of Shipping Time (DHL)

APPENDIX H. HONG KONG ANALYSIS RESULTS

Figure H.1. Boxplot of Primary Carrier Shipping Times (HONG KONG)

Source \ Carrier	DHL	FEDEX
Crane, In	0	4
DDCO	0	1
DDDC	5	4
DDHU	0	1
DDJC	1	24
DDNV	0	20
DDPH	0	4
DDRV	1	0
DDSP	1	10
DDYJ	29	0
TRF Bangor	0	1
TRF Kingsbay	0	1

Table H.1. Number of Source of Supply/Carrier Requisitions in Dataset (HONG KONG)

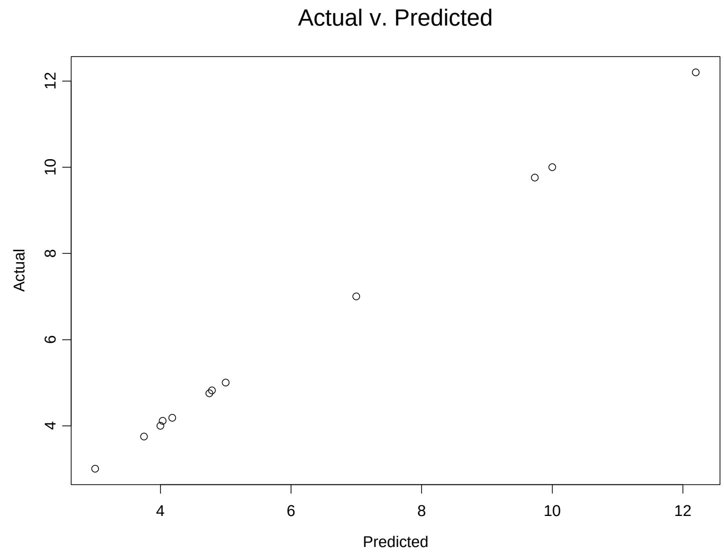


Figure H.2. Plot of Actual v. Predicted Shipping Times (HONG KONG)

Source \ Carrier	DHL	FEDEX
Crane, IN	NA	4.8
DDCO	NA	7.0
DDDC	3.4	5.0
DDHU	NA	4.0
DDJC	6.7	9.9
DDNV	NA	12.2
DDPH	NA	3.8
DDRV	3.0	NA
DDSP	3.4	5.0
DDYJ	4.2	NA
TRF Bangor	NA	5.0
TRF Kings Bay	NA	10.0

Table H.2. Predicted Shipping Time Values (HONG KONG)

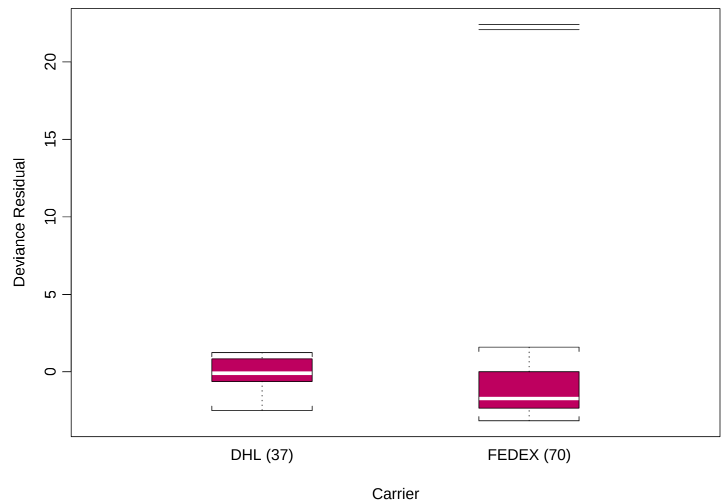


Figure H.3. Boxplot of Carrier Residual Deviances (HONG KONG)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX I. KINGS BAY ANALYSIS RESULTS

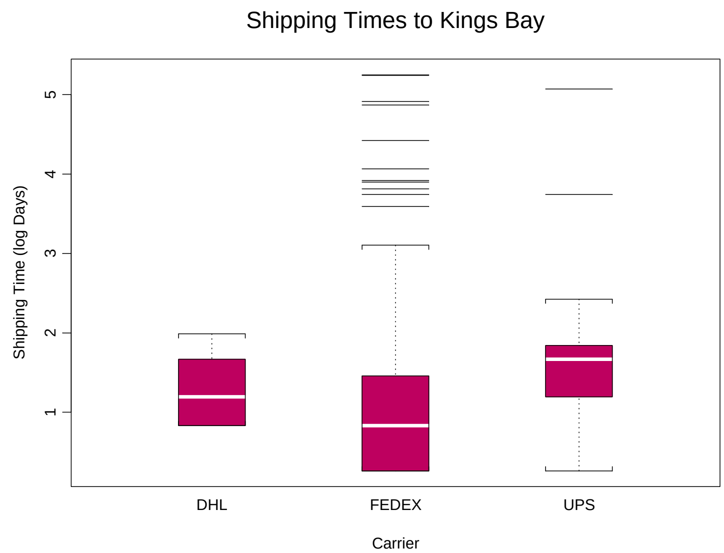


Figure I.1. Boxplot of Primary Carrier Shipping Times (KINGS BAY)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	0	4	0
DDAA	0	1	0
DDAG	0	4	0
DDBC	0	1	0
DDCN	0	2	0
DDCO	0	7	0
DDDC	0	19	0
DDDE	0	0	1
DDHU	0	2	0
DDJC	0	97	4
DDJF	0	19	4
DDNV	1	200	25
DDOO	0	4	0
DDPH	6	49	1
DDPW	0	37	0
DDRV	0	35	0
DDSI	0	16	0
DDSP	0	273	25
DDYJ	4	15	0
TRF Bangor	1	86	2
TRF Kings Bay	0	2	0
USS EMORY S LAND	0	1	0
USS FRANK CABLE	0	1	0

Table I.1. Number of Source of Supply/Carrier Requisitions in Dataset (KINGS BAY)

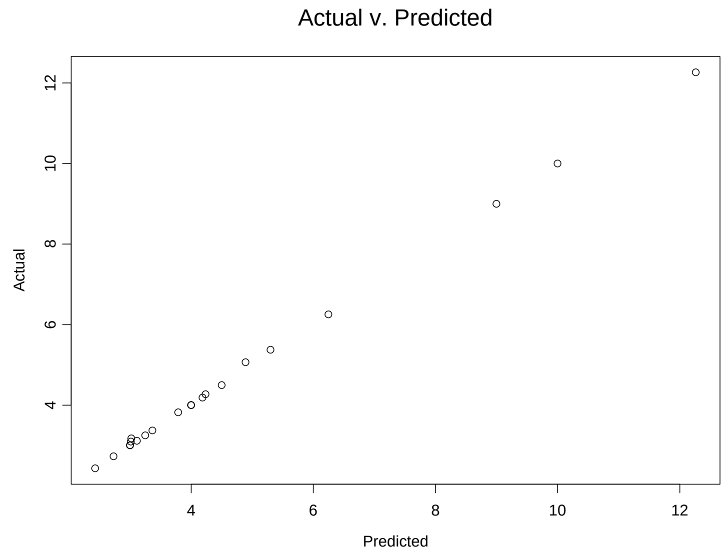


Figure I.2. Plot of Actual v. Predicted Shipping Times (KINGS BAY)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	NA	6.3	NA
DDAA	NA	4.0	NA
DDAG	NA	3.3	NA
DDBC	NA	4.0	NA
DDCN	NA	3.0	NA
DDCO	NA	2.4	NA
DDDC	NA	12.3	NA
DDDE	NA	NA	10.0
DDHU	NA	3.0	NA
DDJC	NA	5.1	11.0
DDJF	NA	2.6	5.7
DDNV	4.2	4.5	9.7
DDOO	NA	3.0	NA
DDPH	3.9	4.2	9.0
DDPW	NA	2.7	NA
DDRV	NA	3.1	NA
DDSI	NA	4.2	NA
DDSP	NA	2.8	6.1
DDYJ	3.2	3.4	NA
TRF Bangor	3.5	3.7	8.0
TRF Kings Bay	NA	4.5	NA
USS EMORY S LAND	NA	9.0	NA
USS FRANK CABLE	NA	4.0	NA

Table I.2. Predicted Shipping Time Values (KINGS BAY)

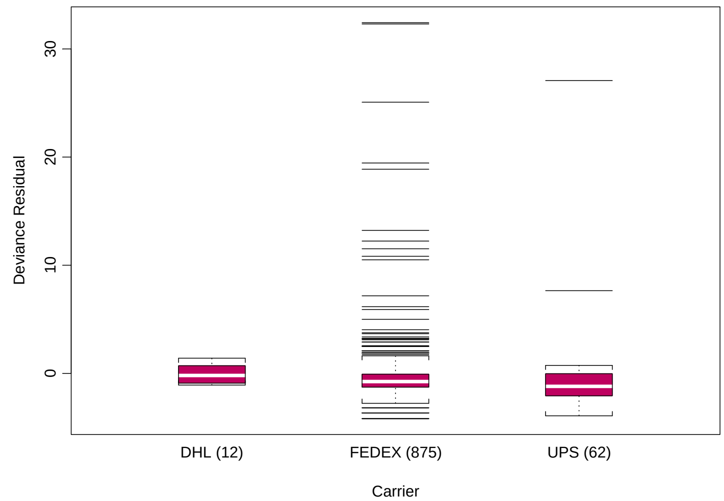


Figure I.3. Boxplot of Carrier Residual Deviances (KINGS BAY)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX J. MAYPORT ANALYSIS RESULTS

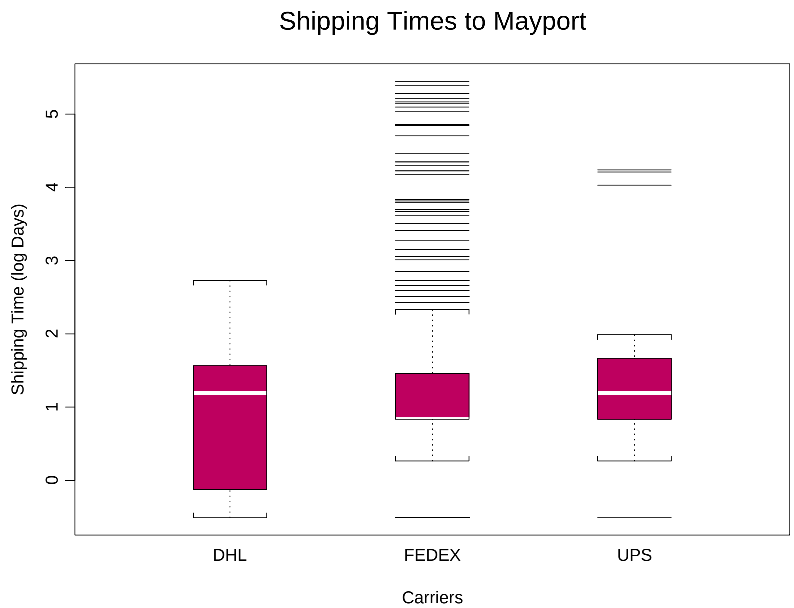


Figure J.1. Boxplot of Primary Carrier Shipping Times (MAYPORT)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	0	105	0
DDAA	0	1	1
DDAG	0	2	0
DDBC	0	1	0
DDCO	0	11	0
DDDC	0	110	0
DDHU	0	1	0
DDJC	1	210	3
DDJF	0	25	2
DDNV	0	474	20
DDOO	0	1	0
DDPH	9	31	0
DDPW	0	13	0
DDRV	0	36	0
DDSI	0	11	0
DDSP	1	480	15
DDWG	0	2	0
DDYJ	9	46	0
TRF Bangor	0	3	0
TRF Kings Bay	0	4	0

Table J.1. Number of Source of Supply/Carrier Requisitions in Dataset (MAYPORT)

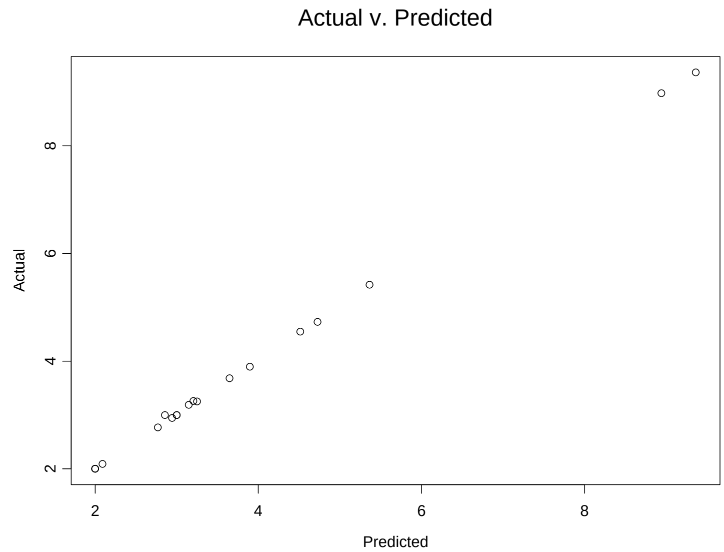


Figure J.2. Plot of Actual v. Predicted Shipping Times (MAYPORT)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	NA	3.9	NA
DDAA	NA	2.1	3.9
DDAG	NA	2.0	NA
DDBC	NA	2.0	NA
DDCO	NA	2.1	NA
DDDC	NA	4.7	NA
DDHU	NA	2.0	NA
DDJC	6.0	8.9	16.7
DDJF	NA	3.1	5.8
DDNV	NA	3.6	6.7
DDOO	NA	2.0	NA
DDPH	2.3	3.4	NA
DDPW	NA	2.8	NA
DDRV	NA	2.9	NA
DDSI	NA	9.4	NA
DDSP	3.0	4.4	8.3
DDWG	NA	3.0	NA
DDYJ	3.9	5.7	NA
TRF Bangor	NA	3.0	NA
TRF Kings Bay	NA	3.3	NA

Table J.2. Predicted Shipping Time Values (MAYPORT)

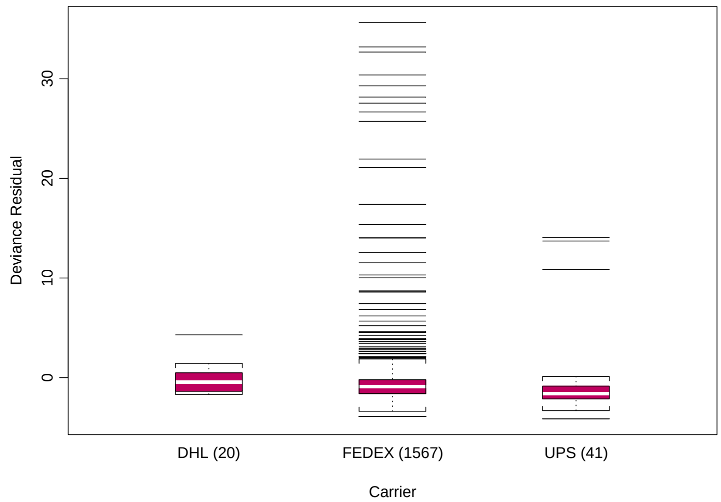


Figure J.3. Boxplot of Carrier Residual Deviances (MAYPORT)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX K. MILDENHALL ANALYSIS RESULTS

Figure K.1. Boxplot of primary Carrier Shipping Times (MILDENHALL)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	7	2	0
DDDC	3	6	0
DDJC	1	23	0
DDNV	3	40	10
DDPH	1	1	0
DDPW	2	1	0
DDRV	0	2	0
DDSI	1	6	0
DDSP	20	54	3
DDYJ	4	0	0
TRF Bangor	0	3	0

Table K.1. Number of Source of Supply/Carrier Requisitions in Dataset (MILDENHALL)

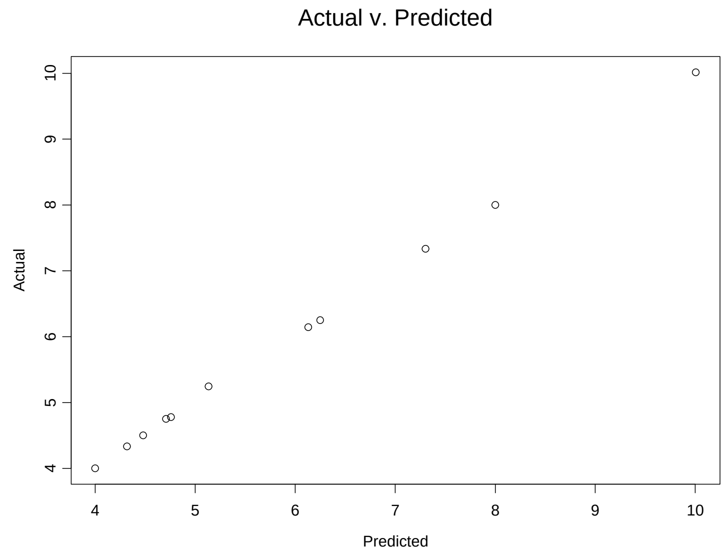


Figure K.2. Plot of Actual v. Predicted Shipping Times (MILDENHALL)

Source \ Carrier	DHL	FEDEX	UPS
Crane, In	4.1	5.0	NA
DDDC	4.2	5.1	NA
DDJC	8.3	10.1	NA
DDNV	3.9	4.7	7.7
DDPH	4.1	4.9	NA
DDPW	6.9	8.3	NA
DDRV	NA	8.0	NA
DDSI	5.2	6.3	NA
DDSP	4.0	4.9	7.8
DDYJ	6.3	NA	NA
TRF Bangor	NA	4.0	NA

Table K.2. Predicted Shipping Time Values (MILDENHALL)

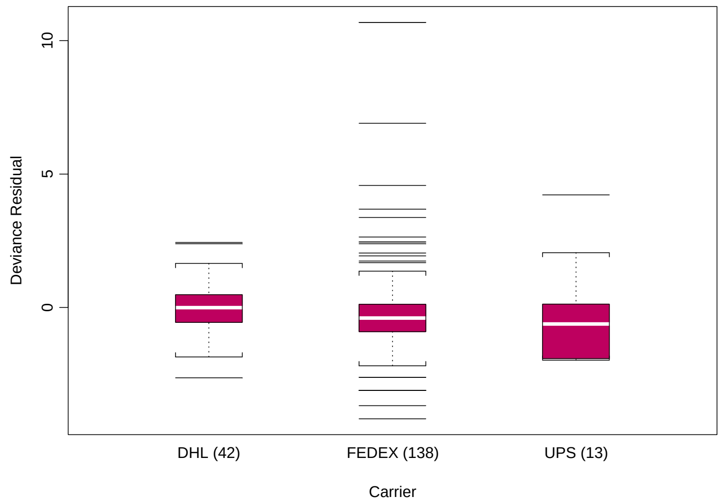


Figure K.3. Boxplot of Carrier Residual Deviances (MILDENHALL)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX L. NORFOLK ANALYSIS RESULTS

Figure L.1. Boxplot of primary Carrier Shipping Times (NORFOLK)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	1	106	1
DDBC	0	4	0
DDCO	0	11	0
DDCT	0	1	0
DDDC	1	119	1
DDHU	0	2	0
DDJC	1	192	9
DDJF	0	30	3
DDNV	0	42	2
DDOO	0	1	0
DDPH	2	43	1
DDPW	0	19	0
DDRT	0	3	0
DDRV	3	40	1
DDSI	4	33	0
DDSP	10	381	85
DDYJ	2	39	0
TRF Bangor	0	12	0
TRF Kings Bay	0	11	0
USS FRANK CABLE	1	0	0

Table L.1. Number of Source of Supply/Carrier Requisitions in Dataset (NORFOLK)

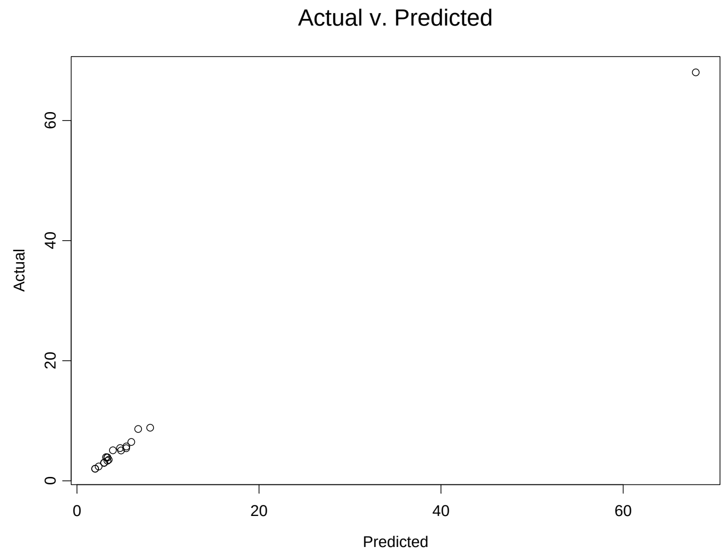


Figure L.2. Plot of Actual v. Predicted Shipping Times (NORFOLK)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	32.6	5.3	24.1
DDBC	NA	2.0	NA
DDCO	NA	2.4	NA
DDCT	NA	3.0	NA
DDDC	29.2	4.7	21.5
DDHU	NA	3.5	NA
DDJC	46.0	7.4	34.0
DDJF	NA	2.9	13.4
DDNV	NA	5.6	25.4
DDOO	NA	2.0	NA
DDPH	18.5	3.0	13.6
DDPW	NA	5.4	NA
DDRT	NA	3.0	NA
DDRV	16.8	2.7	12.4
DDSI	20.1	3.2	NA
DDSP	30.6	4.9	22.6
DDYJ	26.9	4.3	NA
TRF Bangor	NA	3.0	NA
TRF Kings Bay	NA	3.4	NA
USS FRANK CABLE	68.0	NA	NA

Table L.2. Predicted Shipping Time Values (NORFOLK)

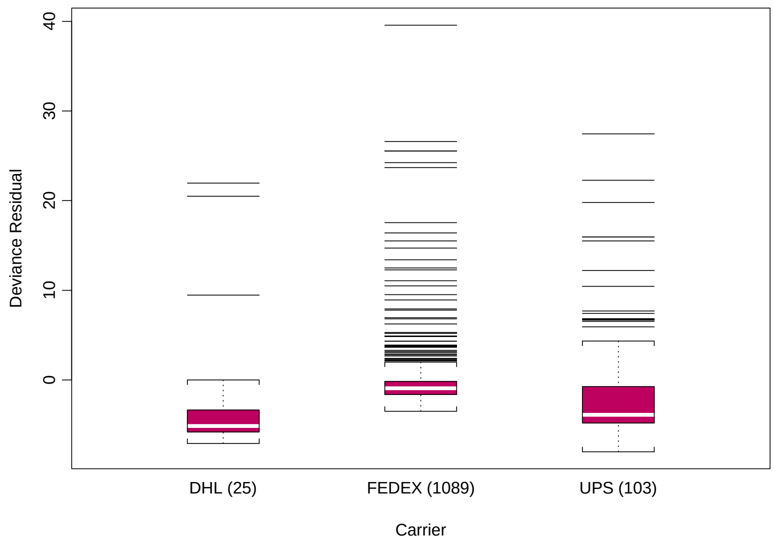


Figure L.3. Boxplot of Carrier Residual Deviances (NORFOLK)

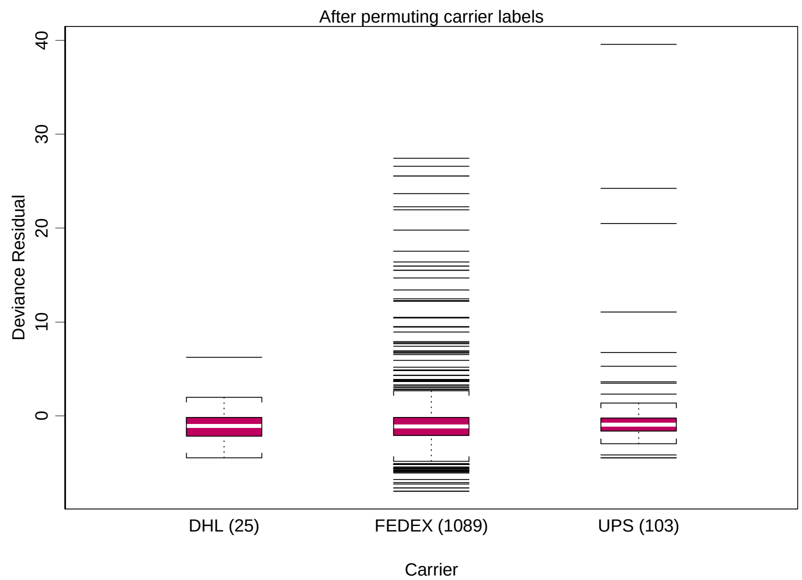


Figure L.4. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (NORFOLK)

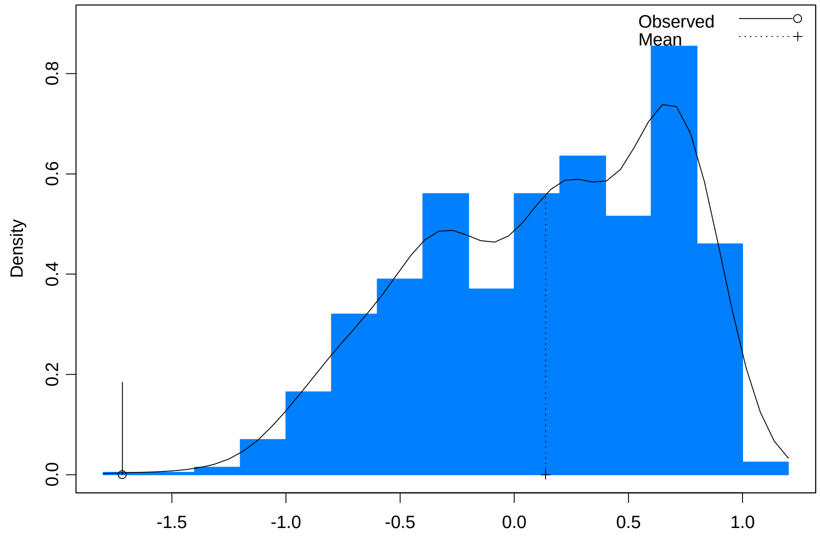


Figure L.5. Permutation Test for Regression of Shipping Time (FEDEX)

APPENDIX M. OKINAWA ANALYSIS RESULTS

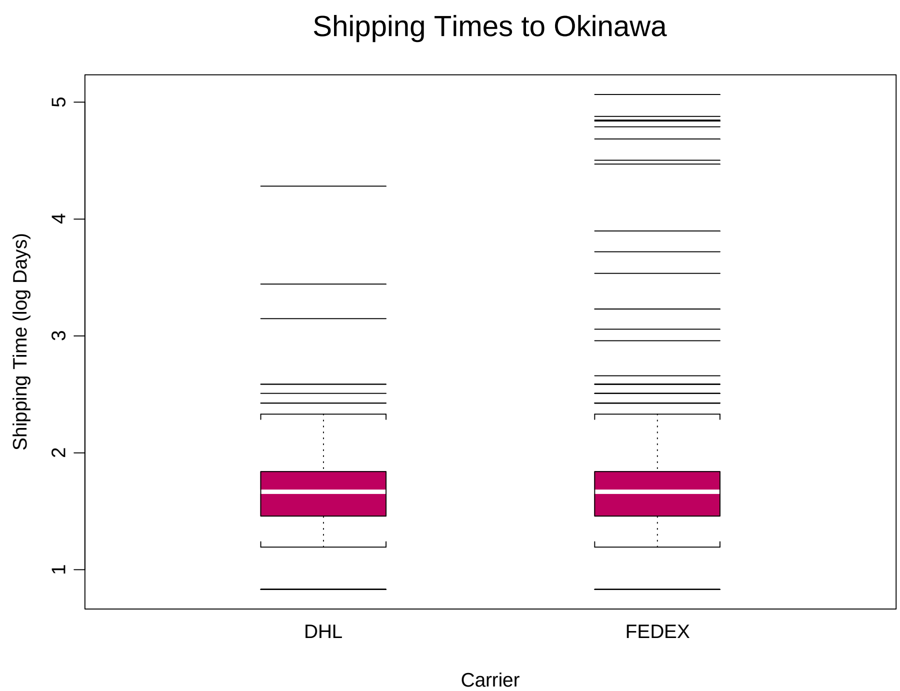


Figure M.1. Boxplot of Primary Carrier Shipping Times (OKINAWA)

Source \ Carrier	DHL	FEDEX
Crane,IN	7	29
DDBC	2	2
DDCO	0	1
DDDC	0	30
DDDE	0	1
DDHU	1	2
DDJC	17	150
DDJF	1	4
DDNV	2	37
DDPH	5	34
DDPW	1	4
DDRT	0	2
DDRV	13	4
DDSI	0	3
DDSP	49	45
DDYJ	4	4
TRF Kings Bay	0	1

Table M.1. Number of Source of Supply/Carrier Requisitions in Dataset (OKINAWA)

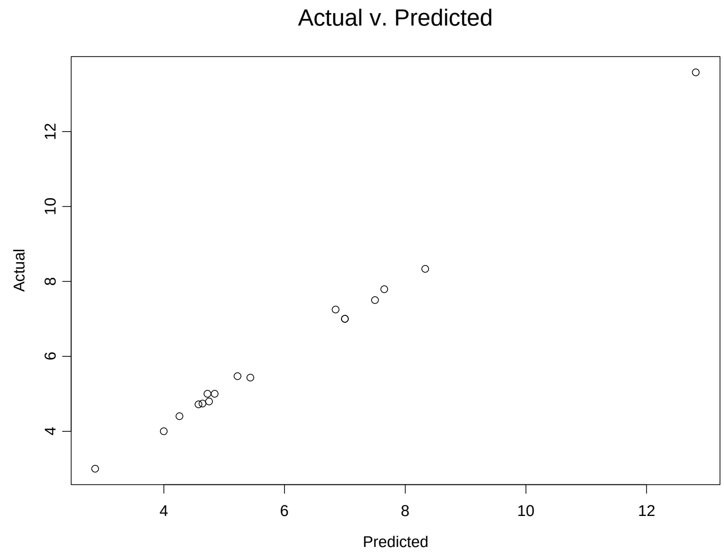


Figure M.2. Plot of Actual v. Predicted Shipping Times (OKINAWA)

Source \ Carrier	DHL	FEDEX
Crane,IN	2.6	5.2
DDBC	3.4	6.6
DDCO	NA	7.0
DDDC	NA	5.4
DDDE	NA	7.0
DDHU	1.8	3.6
DDJC	4.1	8.2
DDJF	2.5	4.9
DDNV	2.5	4.9
DDPH	2.6	5.1
DDPW	2.8	5.5
DDRT	NA	7.5
DDRV	4.4	8.8
DDSI	NA	8.3
DDSP	9.2	18.3
DDYJ	4.9	9.6
TRF Kings Bay	NA	4.0

Table M.2. Predicted Shipping Time Values (OKINAWA)

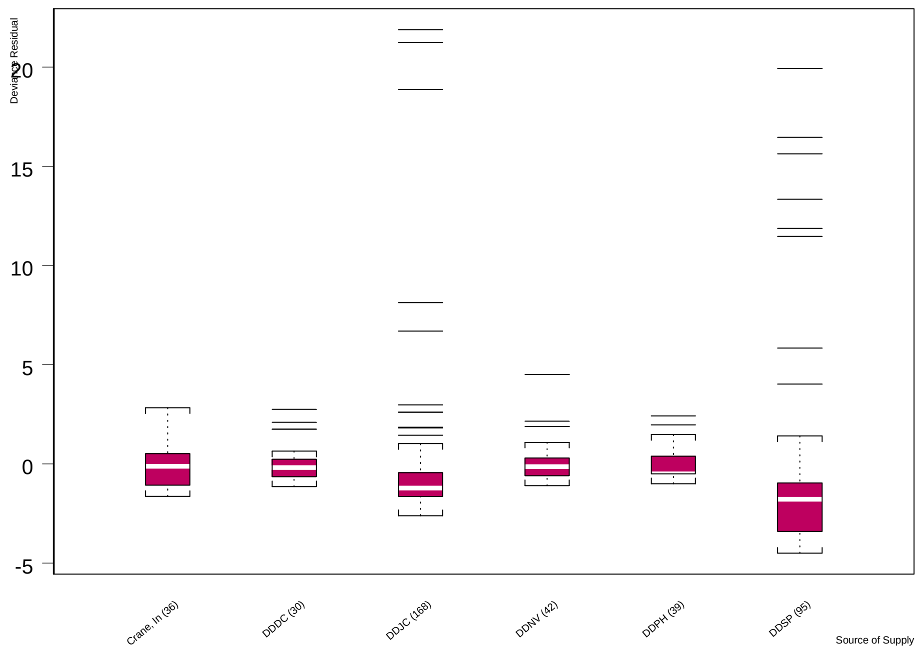


Figure M.3. Boxplot of Source of Supply Residual Deviances (OKINAWA)

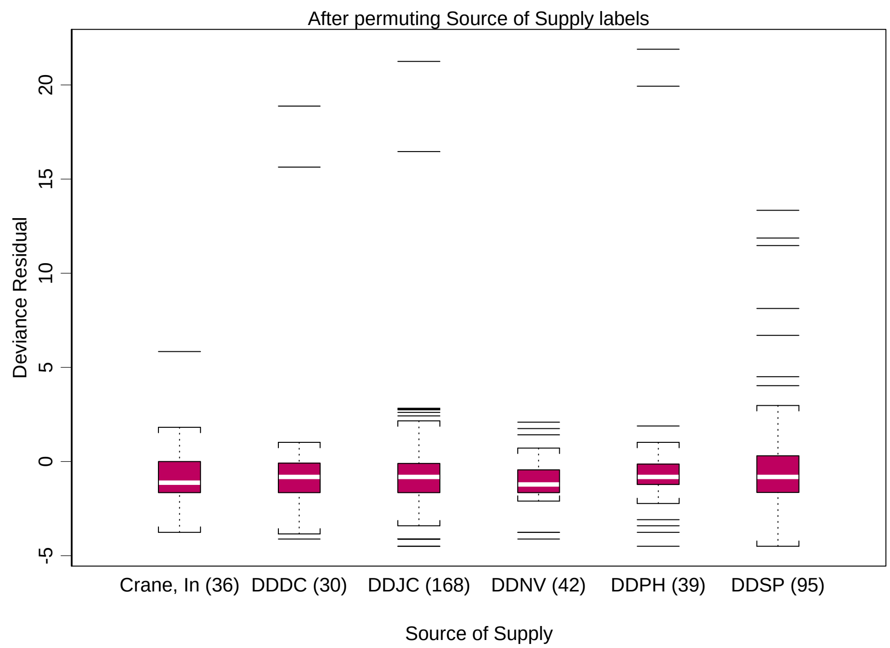


Figure M.4. Boxplot of Source of Supply Residual Deviances after Permuting Source of Supply Labels (OKINAWA)

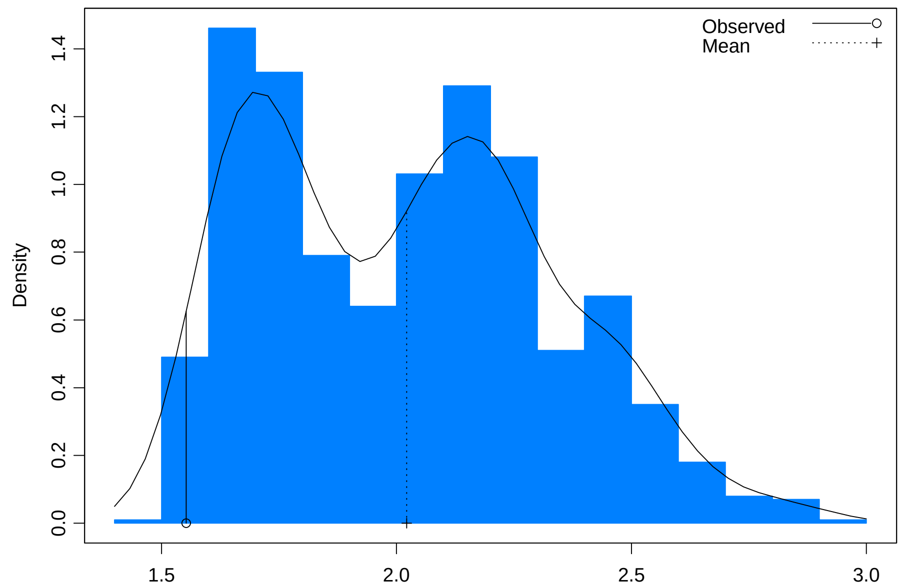


Figure M.5. Permutation Test for Regression of Shipping Time (Crane, IN SOURCE OF SUPPLY)

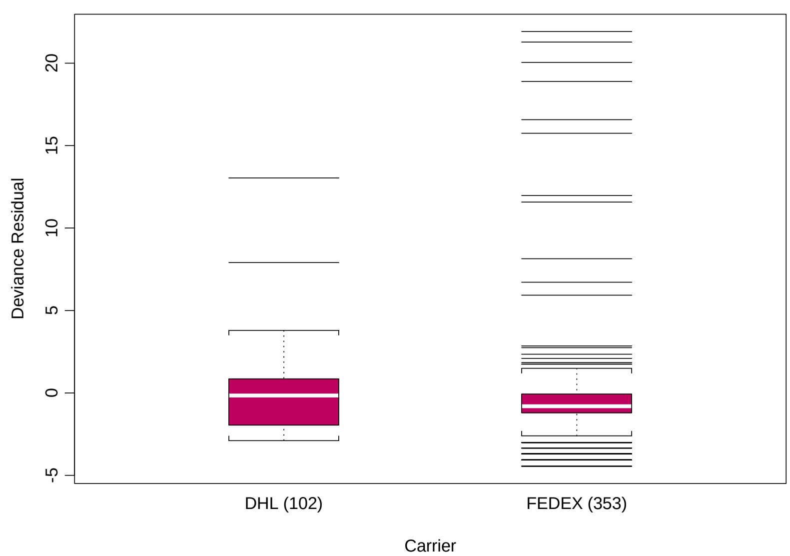


Figure M.6. Boxplot of Carrier Residual Deviances (OKINAWA)

APPENDIX N. PEARL HARBOR ANALYSIS RESULTS

Figure N.1. Boxplot of Primary Carrier Shipping Times (PEARL HARBOR)

Source \ Carrier	DHL	FEDEX	LANDSTAR/ Military Air Cargo	NATIONAL AIR CARGO	PILOT AIR	UPS
Crane,IN	0	154	0	0	1	1
DDAG	0	1	0	0	0	0
DDBC	0	9	0	0	0	3
DDCN	0	1	0	0	0	0
DDCO	0	11	0	0	0	0
DDDC	0	196	0	0	1	1
DDDE	0	0	0	0	0	1
DDHU	0	4	0	0	0	0
DDJC	2	720	0	13	1	34
DDJF	0	24	0	0	1	1
DDNV	3	363	0	0	0	34
DDOO	0	1	0	0	0	0
DDPH	4	27	0	0	0	0
DDPW	0	89	1	0	0	1
DDRT	0	1	0	0	0	0
DDRV	0	43	0	0	0	0
DDSI	1	52	0	0	0	0
DDSP	3	457	0	0	0	16
DDWG	0	1	0	0	0	0
DDYJ	22	75	0	0	0	0
TRF Bangor	2	175	18	0	4	1
TRF Kings Bay	0	45	0	0	5	0
USS EMORY S LAND	1	1	0	0	0	0
USS FRANK CABLE	4	1	0	0	0	0

Table N.1. Number of Source of Supply/Carrier Requisitions in Dataset (PEARL HARBOR)

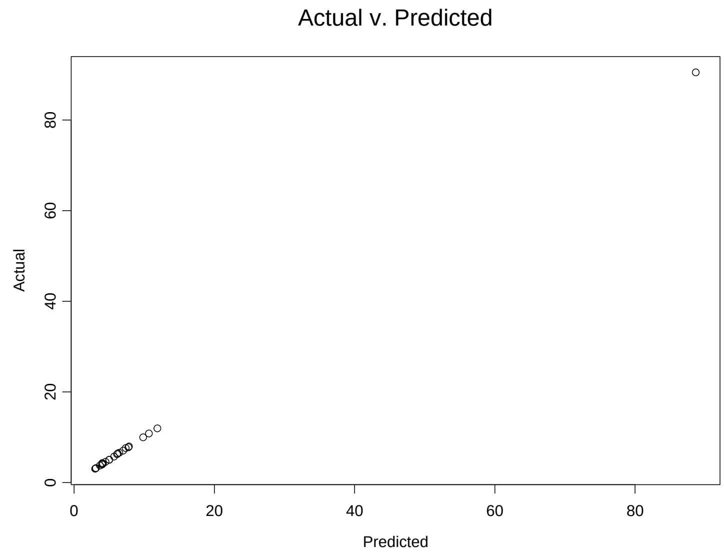


Figure N.2. Plot of Actual v. Predicted Shipping Times (PEARL HARBOR)

Source \ Carrier	DHL	FEDEX	LANDSTAR/ Military Air Cargo	NATIONAL AIR CARGO	PILOT AIR	UPS
Crane,IN	NA	5.7	NA	NA	3.1	12.1
DDAG	NA	5.0	NA	NA	NA	NA
DDBC	NA	3.3	NA	NA	NA	7.0
DDCN	NA	7.0	NA	NA	NA	NA
DDCO	NA	3.1	NA	NA	NA	NA
DDDC	NA	4.1	NA	NA	2.3	8.7
DDDE	NA	NA	NA	NA	NA	5.0
DDHU	NA	7.8	NA	NA	NA	NA
DDJC	9.4	6.3	NA	3.7	3.4	13.3
DDJF	NA	6.2	NA	NA	3.4	13.1
DDNV	10.3	6.9	NA	NA	NA	14.6
DDOO	NA	4.0	NA	NA	NA	NA
DDPH	11.2	7.4	NA	NA	NA	NA
DDPW	NA	4.5	3.0	NA	NA	9.5
DDRT	NA	3.0	NA	NA	NA	NA
DDRV	NA	3.7	NA	NA	NA	NA
DDSI	17.7	11.8	NA	NA	NA	NA
DDSP	14.4	9.6	NA	NA	NA	20.2
DDWG	NA	4.0	NA	NA	NA	NA
DDYJ	5.5	3.7	NA	NA	NA	NA
TRF Bangor	4.9	3.3	2.2	NA	1.8	6.9
TRF Kings Bay	NA	6.5	NA	NA	3.5	NA
USS EMORY S LAND	108.6	72.4	NA	NA	NA	NA
USS FRANK CABLE	11.6	7.7	NA	NA	NA	NA

Table N.2. Predicted Shipping Time Values (PEARL HARBOR)

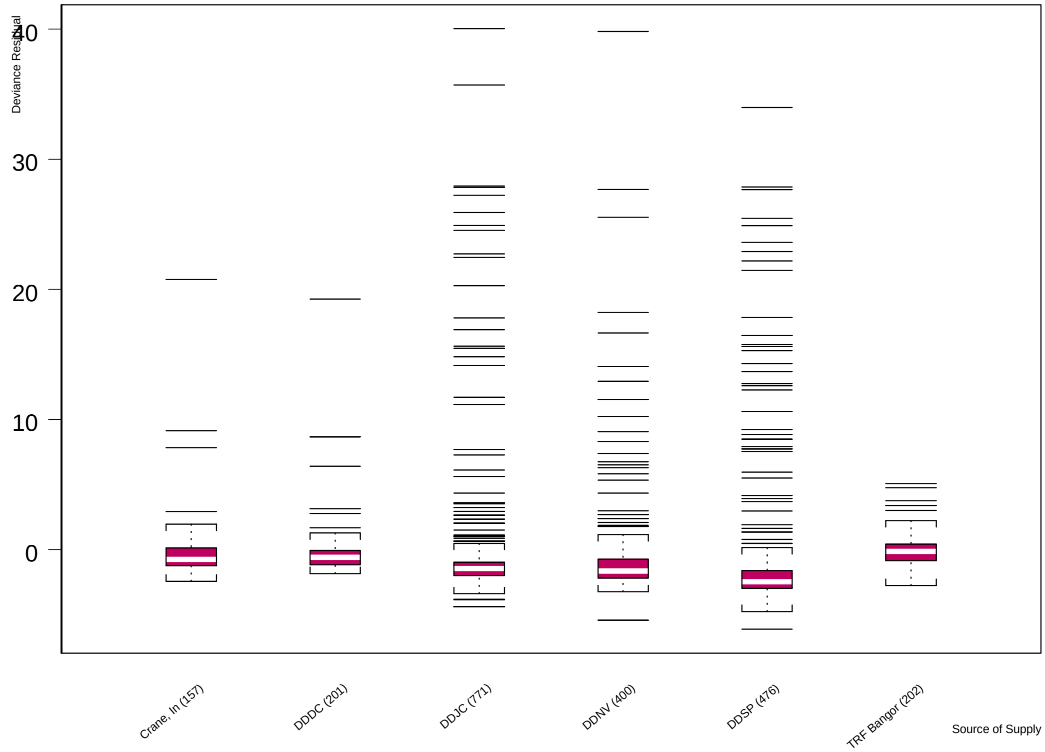


Figure N.3. Boxplot of Source of Supply Residual Deviances (PEARL HARBOR)

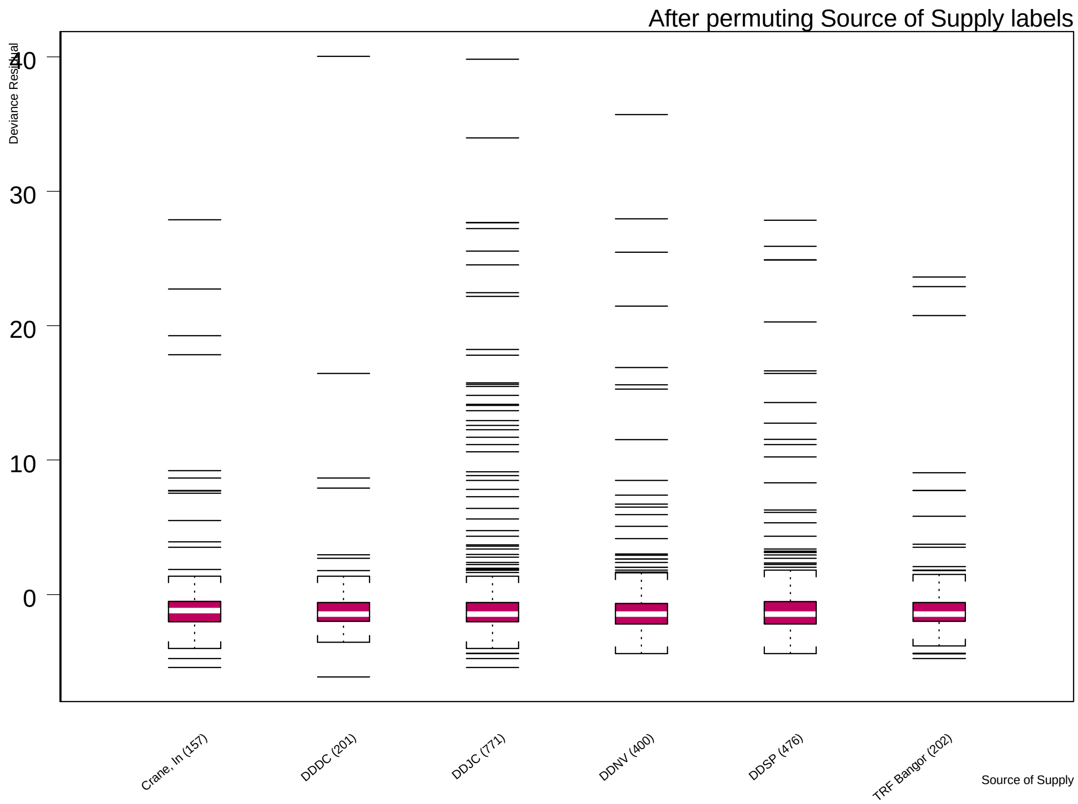


Figure N.4. Boxplot of Source of Supply Residual Deviances After Permuting Source of Supply Labels (PEARL HARBOR)

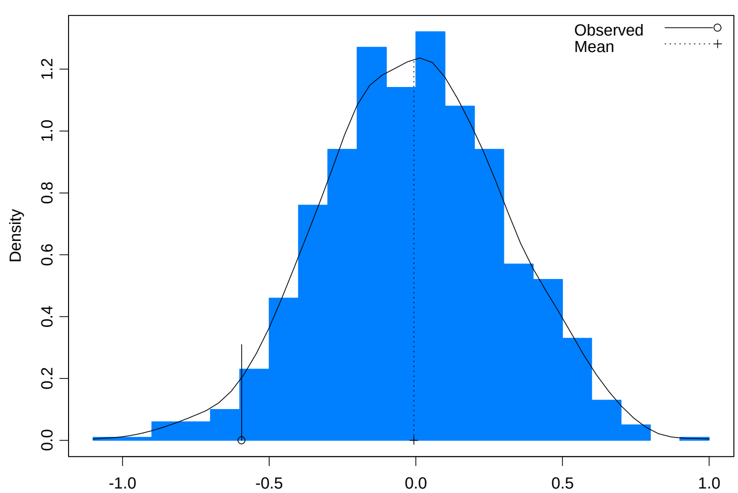


Figure N.5. Permutation Test for Regression of Shipping Time (TRF Bangor SOURCE OF SUPPLY)

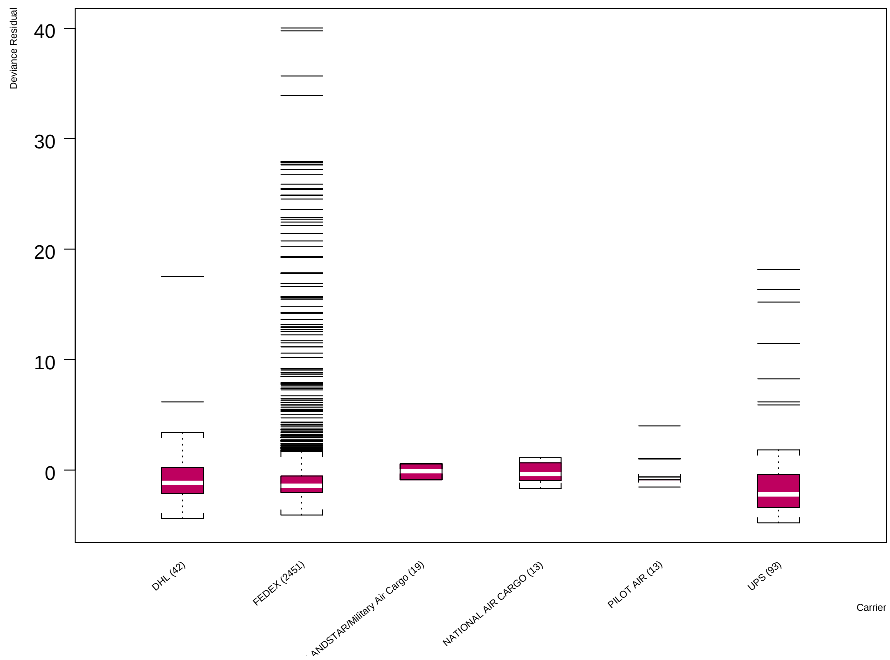


Figure N.6. Boxplot of Carrier Residual Deviances (PEARL HARBOR)

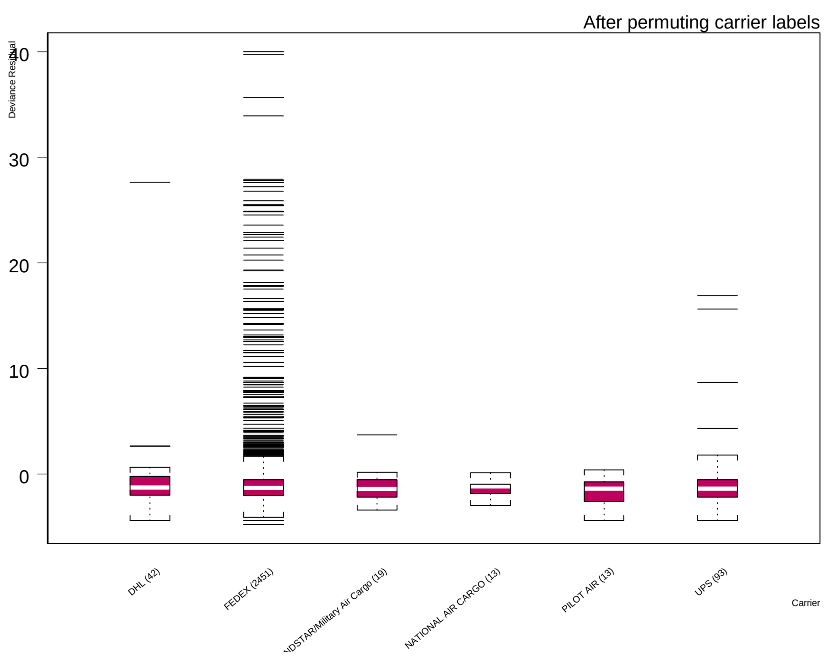


Figure N.7. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (PEARL HARBOR)

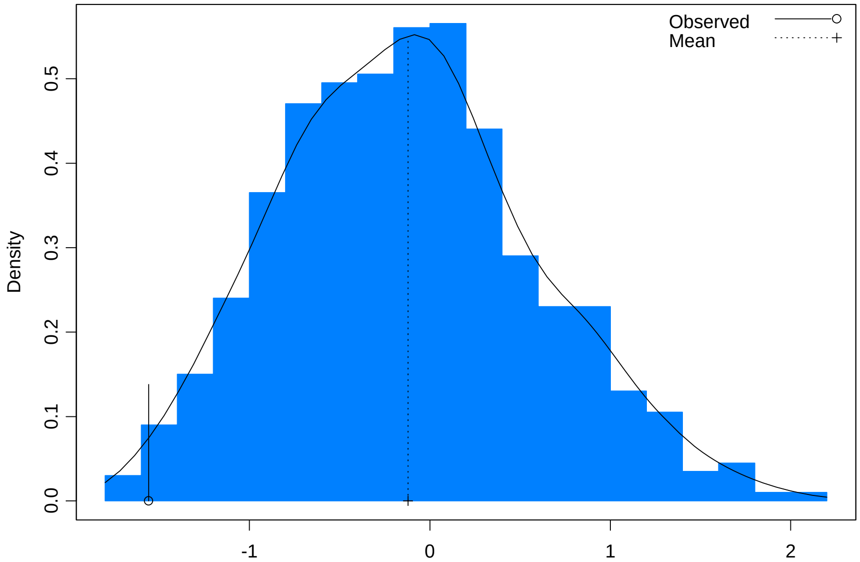


Figure N.8. Permutation Test for Regression of Shipping Time (LANDSTAR/MILITARY AIR CARGO)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX O. ROTA ANALYSIS RESULTS

Figure O.1. Boxplot of Primary Carrier Shipping Times (ROTA)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	2	5	0
DDCN	0	0	1
DDDC	3	7	0
DDDE	0	1	0
DDJC	1	9	25
DDJF	2	1	0
DDNV	22	37	10
DDPH	2	9	0
DDRV	0	2	0
DDSI	2	10	0
DDSP	18	56	12
DDYJ	9	0	0
TRF Kings Bay	0	2	0
USS FRANK CABLE	1	0	0

Table O.1. Number of Source of Supply/Carrier Requisitions in Dataset (ROTA)

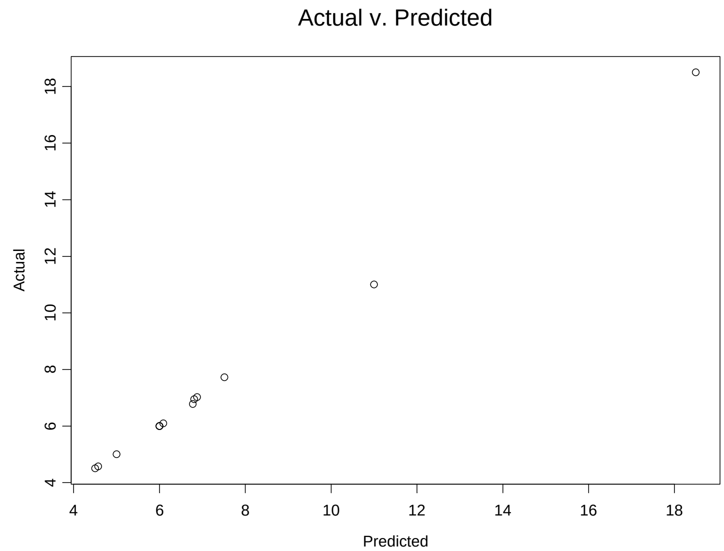


Figure O.2. Plot of Actual v. Predicted Shipping Times (ROTA)

Source \ Carrier	DHL	FEDEX	UPS
Crane, In	4.6	4.6	NA
DDCN	NA	NA	6.0
DDDC	5.0	5.0	NA
DDDE	NA	6.0	NA
DDJC	5.2	5.1	8.8
DDJF	6.0	6.0	NA
DDNV	6.4	6.3	10.9
DDPH	6.1	6.1	NA
DDRV	NA	6.0	NA
DDSI	18.7	18.5	NA
DDSP	6.4	6.3	10.8
DDYJ	6.8	NA	NA
TRF Kings Bay	NA	4.5	NA
USS FRANK CABLE	11.0	NA	NA

Table O.2. Predicted Shipping Time Values (ROTA)

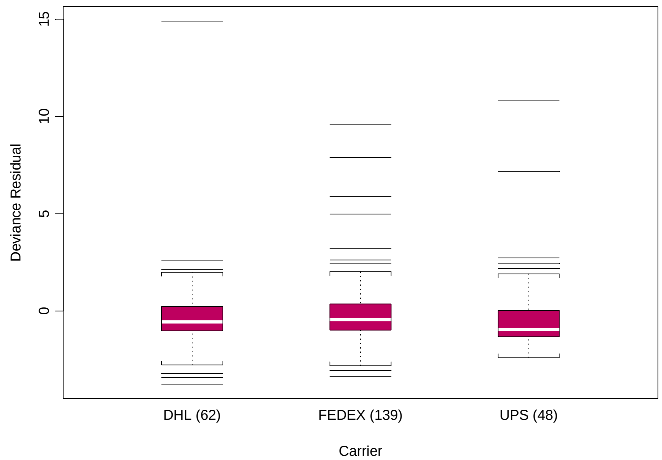


Figure O.3. Boxplot of Carrier Residual Deviances (ROTA)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX P. SAN DIEGO ANALYSIS RESULTS

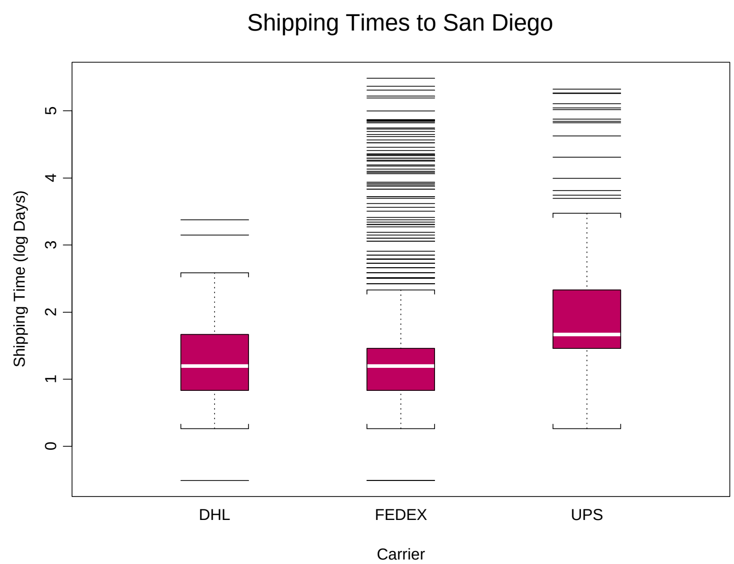


Figure P.1. Boxplot of Primary Carrier Shipping Times (SAN DIEGO)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	0	239	1
DDAG	0	2	2
DDBC	0	11	2
DDCO	0	16	0
DDCT	0	2	0
DDDC	5	25	0
DDHU	0	1	0
DDJC	0	971	46
DDJF	0	35	5
DDNV	1	507	56
DDPH	53	115	3
DDPW	0	117	0
DDRV	0	41	0
DDSI	1	39	0
DDSP	1	472	24
DDTP	0	0	1
DDWG	0	0	2
DDYJ	13	83	1
TRF Bangor	0	76	0
TRF Kings Bay	0	11	0
USS EMORY S LAND	0	2	0
USS FRANK CABLE	4	1	0

Table P.1. Number of Source of Supply/Carrier Requisitions in Dataset (SAN DIEGO)

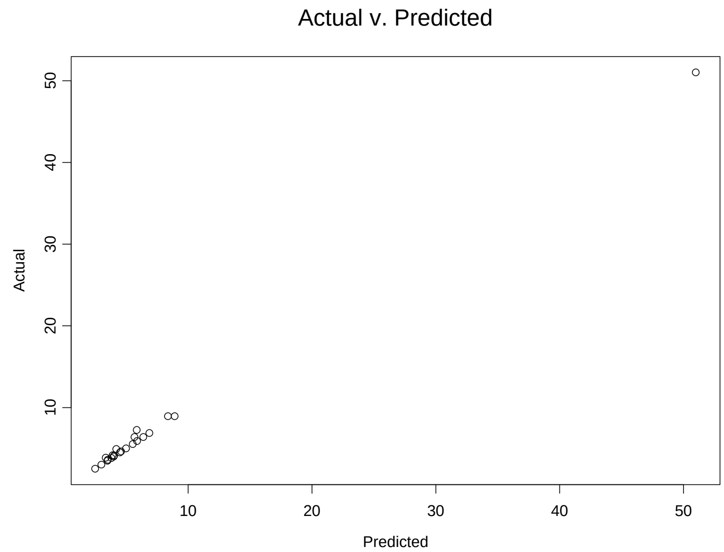


Figure P.2. Plot of Actual v. Predicted Shipping Times (SAN DIEGO)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	NA	4.6	17.6
DDAG	NA	3.0	11.5
DDBC	NA	3.4	13.2
DDCO	NA	3.5	NA
DDCT	NA	2.5	NA
DDDC	9.8	8.8	NA
DDHU	NA	4.0	NA
DDJC	NA	3.7	14.2
DDJF	NA	2.8	10.9
DDNV	5.5	5.0	19.2
DDPH	3.7	3.3	12.9
DDPW	NA	4.5	NA
DDRV	NA	6.9	NA
DDSI	6.2	5.5	NA
DDSP	8.8	7.9	30.3
DDTP	NA	NA	3.0
DDWG	NA	NA	5.0
DDYJ	4.4	3.9	15.2
TRF Bangor	NA	5.9	NA
TRF Kings Bay	NA	3.8	NA
USS EMORY S LAND	NA	51.0	NA
USS FRANK CABLE	6.5	5.9	NA

Table P.2. Predicted Shipping Time Values (SAN DIEGO)

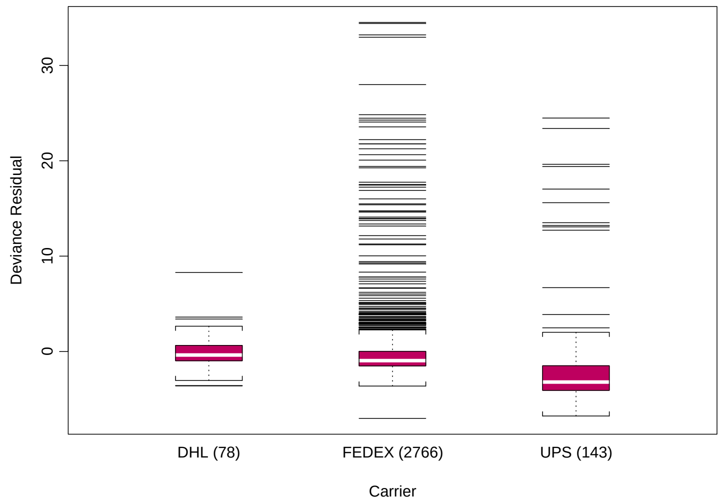


Figure P.3. Boxplot of Carrier Residual Deviances (SAN DIEGO)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX Q. SASEBO ANALYSIS RESULTS

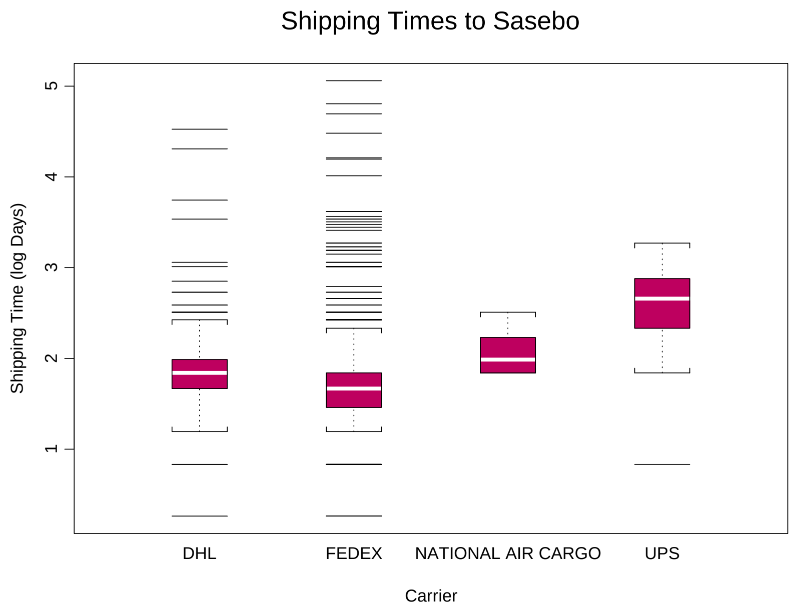


Figure Q.1. Boxplot of Primary Carrier Shipping Times (SASEBO)

Source \ Carrier	DHL	FEDEX	NATIONAL AIR CARGO	UPS
Crane,IN	3	52	0	1
DDBC	3	0	0	1
DDCO	0	7	0	0
DDCT	0	1	0	0
DDDC	2	65	0	0
DDDE	0	1	0	0
DDHU	3	4	0	0
DDJC	68	412	3	2
DDJF	6	2	0	0
DDNV	4	157	2	16
DDPH	8	72	0	1
DDPW	1	10	0	0
DDRT	0	1	0	0
DDRV	12	8	0	0
DDSI	1	4	0	0
DDSP	137	106	6	3
DDWG	2	0	0	0
DDYJ	2	2	0	0
TRF Bangor	0	5	0	0
TRF Kings Bay	0	8	0	0

Table Q.1. Number of Source of Supply/Carrier Requisitions in Dataset (SASEBO)

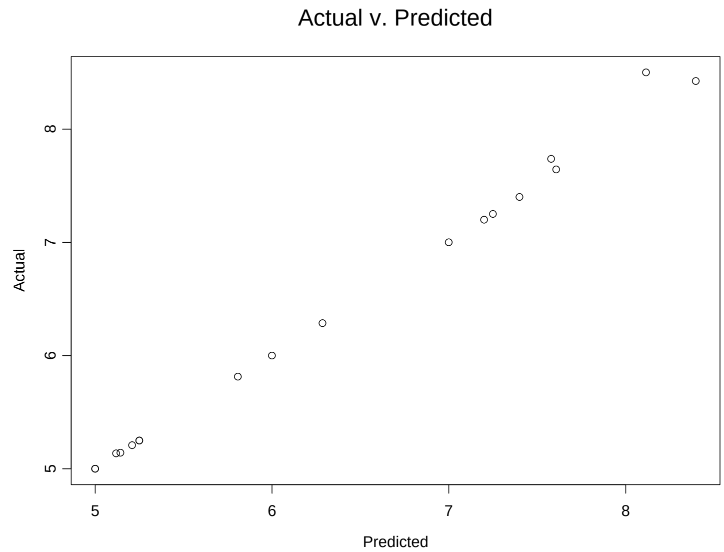


Figure Q.2 Plot of Actual v. Predicted Shipping Times (SASEBO)

Source \ Carrier	DHL	FEDEX	NATIONAL AIR CARGO	UPS
Crane, IN	7.4	7.5	NA	14.5
DDBC	6.9	NA	NA	13.4
DDCO	NA	6.3	NA	NA
DDCT	NA	7.0	NA	NA
DDDC	5.1	5.2	NA	NA
DDDE	NA	5.0	NA	NA
DDHU	5.1	5.2	NA	NA
DDJC	5.7	5.8	6.0	11.1
DDJF	7.2	7.3	NA	NA
DDNV	7.0	7.1	7.4	13.7
DDPH	5.0	5.1	NA	9.8
DDPW	4.9	5.0	NA	NA
DDRT	NA	5.0	NA	NA
DDRV	7.2	7.3	NA	NA
DDSI	7.1	7.2	NA	NA
DDSP	8.3	8.4	8.7	16.1
DDWG	6.0	NA	NA	NA
DDYJ	5.2	5.3	NA	NA
TRF Bangor	NA	7.4	NA	NA
TRF Kings Bay	NA	5.3	NA	NA

Table Q.2. Predicted Shipping Time Values (SASEBO)

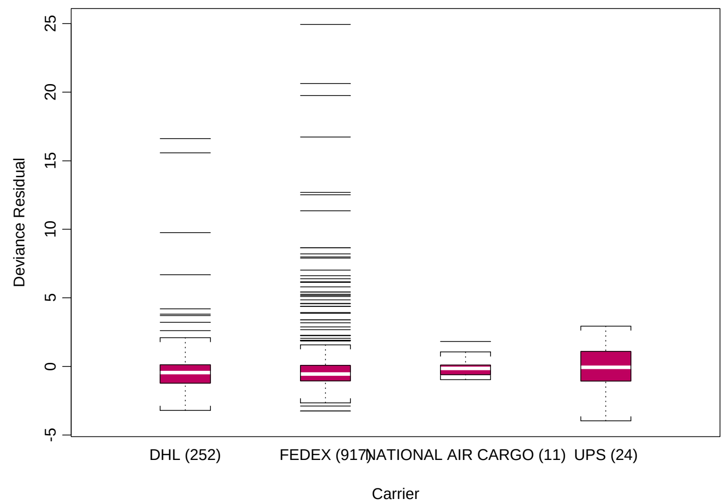


Figure Q.3. Boxplot of Carrier Residual Deviances (SASEBO)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX R. SIGONELLA ANALYSIS RESULTS

Figure R.1. Boxplot of Primary Carrier Shipping Times (SIGONELLA)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	14	13	0
DDAA	1	0	0
DDAG	1	2	0
DDBC	1	2	0
DDCN	0	2	0
DDCO	0	9	0
DDDC	3	27	0
DDDE	0	8	0
DDJC	21	95	1
DDJF	5	7	1
DDNV	29	129	18
DDPH	5	18	0
DDPW	2	1	0
DDRV	14	3	0
DDSI	1	6	0
DDSP	163	122	14
DDWG	1	0	0
DDYJ	24	3	0
TRF Bangor	0	1	0
TRF Kings Bay	0	5	0
USS FRANK CABLE	2	0	0

Table R.1. Number of Source of Supply/Carrier Requisitions in Dataset (SIGONELLA)

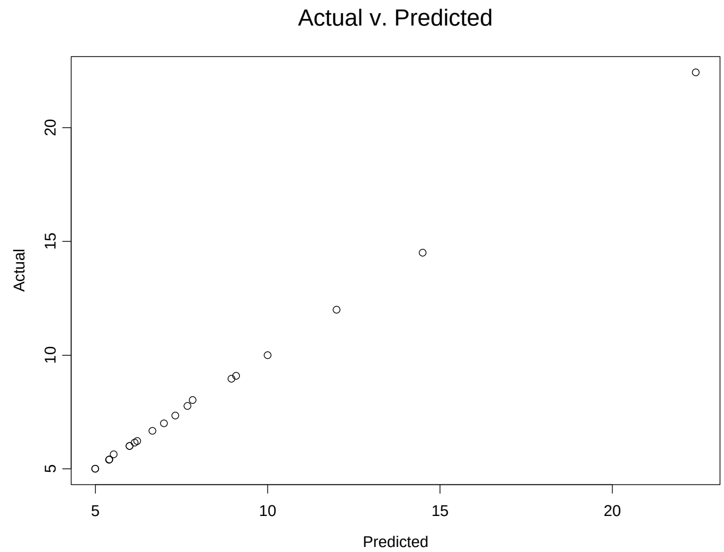


Figure R.2. Plot of Actual v. Predicted Shipping Times (SIGONELLA)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	6.4	5.9	NA
DDAA	12.0	NA	NA
DDAG	7.3	6.8	NA
DDBC	7.0	6.5	NA
DDCN	NA	6.0	NA
DDCO	NA	6.0	NA
DDDC	9.7	9.0	NA
DDDE	NA	6.0	NA
DDJC	7.7	7.2	14.2
DDJF	5.5	5.1	10.1
DDNV	7.8	7.2	14.2
DDPH	9.5	8.8	NA
DDPW	5.1	4.8	NA
DDRV	5.5	5.1	NA
DDSI	23.8	22.2	NA
DDSP	7.7	7.2	14.1
DDWG	10.0	NA	NA
DDYJ	6.3	5.8	NA
TRF Bangor	NA	5.0	NA
TRF Kings Bay	NA	5.4	NA
USS FRANK CABLE	14.5	NA	NA

Table R.2. Predicted Shipping Time Values (SIGONELLA)

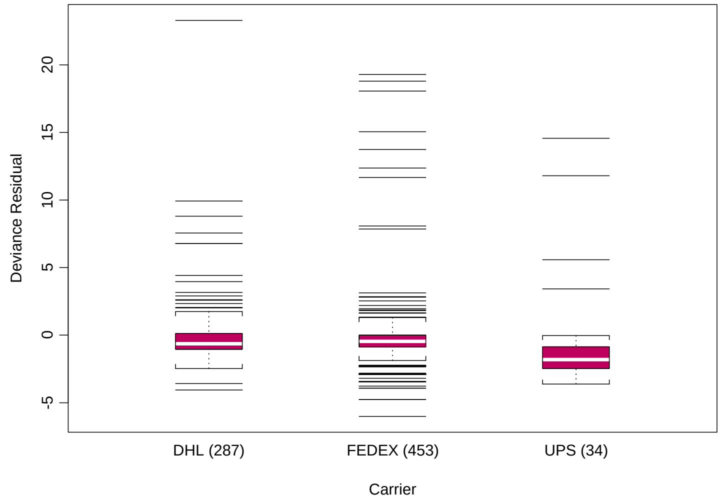


Figure R.3. Boxplot of Carrier Residual Deviances (SIGONELLA)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX S. SINGAPORE ANALYSIS RESULTS

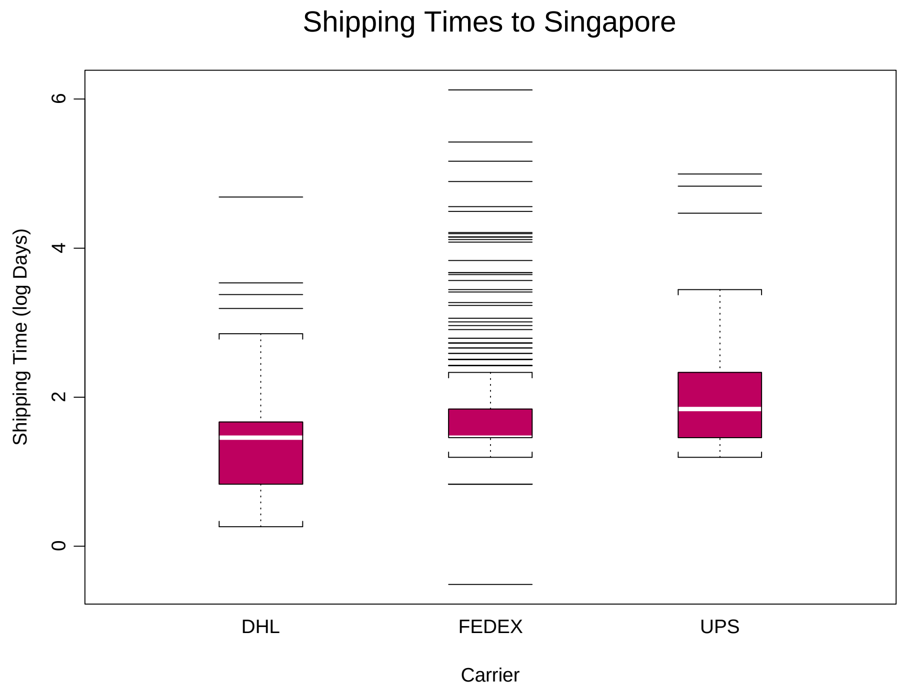


Figure S.1. Boxplot of Primary Carrier Shipping Times (SINGAPORE)

Source \ Carrier	DHL	FEDEX	UPS
Crane,IN	2	26	0
DDAG	0	2	0
DDBC	0	5	0
DDCO	0	6	0
DDDC	18	32	0
DDHU	0	2	0
DDJC	15	278	27
DDJF	0	6	0
DDNV	4	89	5
DDPH	3	26	2
DDPW	0	8	0
DDRV	0	10	0
DDSI	0	3	0
DDSP	58	120	8
DDYJ	298	10	0
TRF Kings Bay	0	2	0

Table S.1. Number of Source of Supply/Carrier Requisitions in Dataset (SINGAPORE)

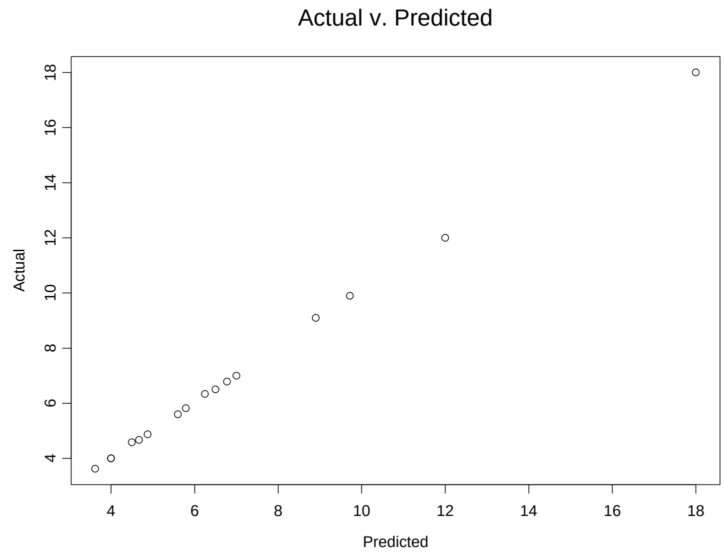


Figure S.2. Plot of Actual v. Predicted Shipping Times (SINGAPORE)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	5.6	6.9	NA
DDAG	NA	12.0	NA
DDBC	NA	5.6	NA
DDCO	NA	4.0	NA
DDDC	5.1	6.2	NA
DDHU	NA	6.5	NA
DDJC	6.9	8.5	16.5
DDJF	NA	4.7	NA
DDNV	5.0	6.1	11.8
DDPH	3.6	4.4	8.5
DDPW	NA	4.9	NA
DDRV	NA	7.0	NA
DDSI	NA	18.0	NA
DDSP	8.2	10.1	19.6
DDYJ	3.6	4.4	NA
TRF Kings Bay	NA	4.0	NA

Table S.2. Predicted Shipping Time Values (SINGAPORE)

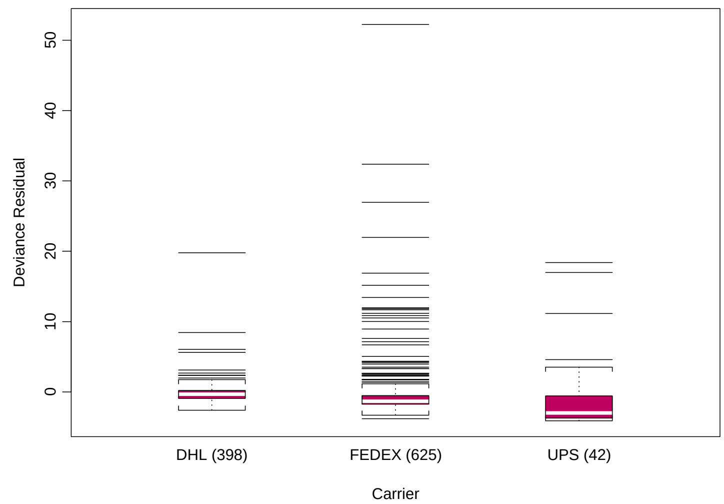


Figure S.3. Boxplot of Carrier Residual Deviances (SINGAPORE)

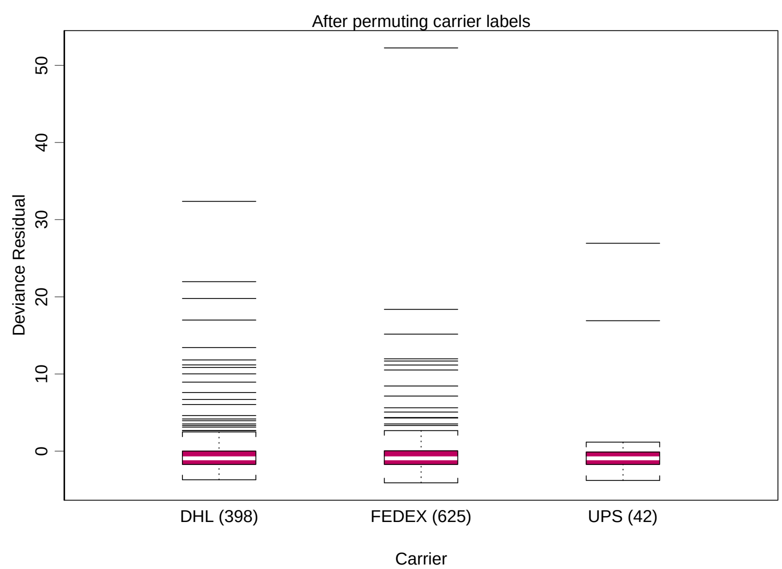


Figure S.4. Boxplot of Carrier Residual Deviances After Permuting Carrier Labels (SINGAPORE)

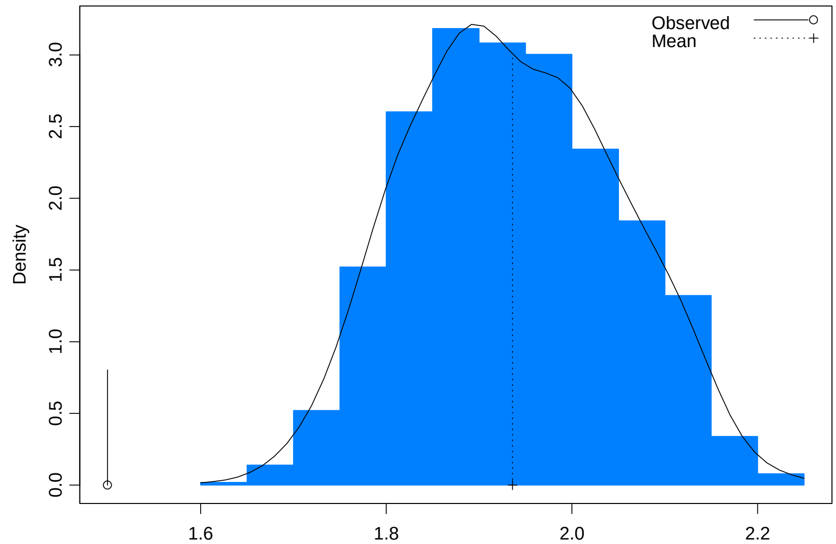


Figure S.5. Permutation Test for Regression of Shipping Time (DHL)

APPENDIX T. YOKOSUKA ANALYSIS RESULTS

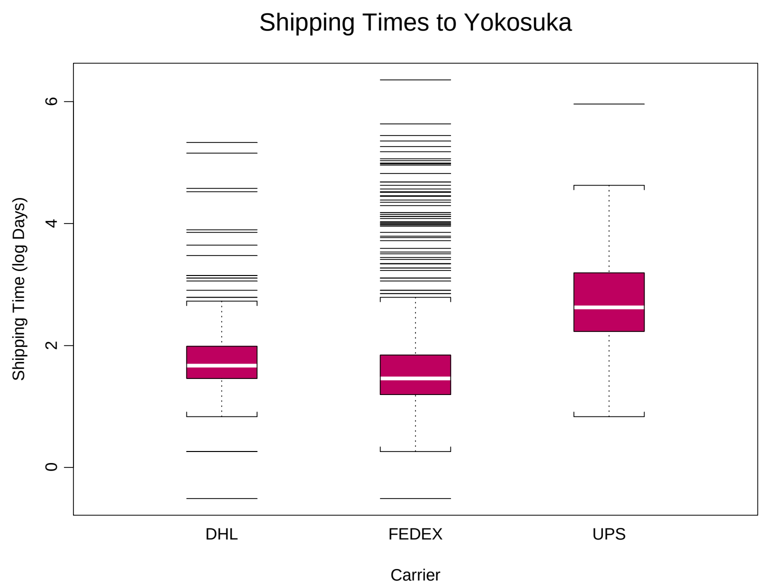


Figure T.1. Boxplot of Primary Carrier Shipping Times (YOKOSUKA)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	7	84	0
DDBC	0	3	0
DDCO	0	10	0
DDCT	0	1	0
DDDC	3	129	1
DDHU	0	6	0
DDJC	43	411	0
DDJF	3	4	1
DDNV	2	231	25
DDPH	61	98	0
DDPW	9	29	1
DDRV	16	3	0
DDSI	2	15	0
DDSP	164	148	5
DDWG	0	1	0
DDYJ	8	10	0
TRF Bangor	3	17	1
TRF Kings Bay	0	12	0
USS EMORY S LAND	0	1	0
USS FRANK CABLE	1	0	0

Table T.1. Number of Source of Supply/Carrier Requisitions in Dataset (YOKOSUKA)

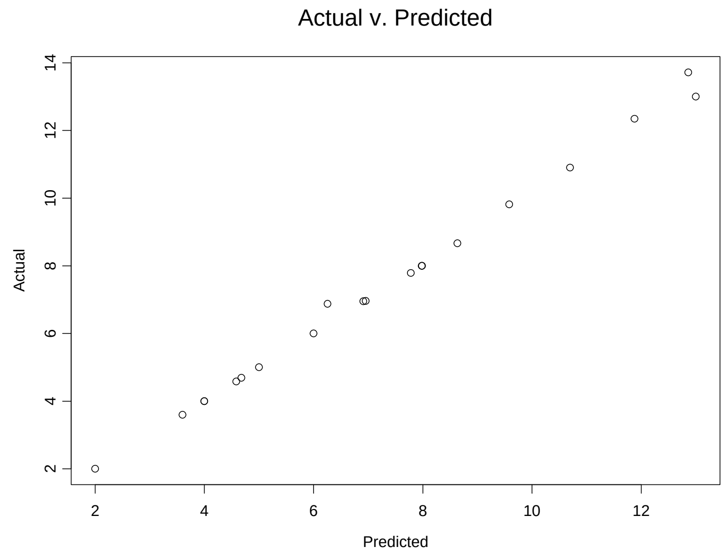


Figure T.2. Plot of Actual v. Predicted Shipping Times (YOKOSUKA)

Source \ Carrier	DHL	FEDEX	UPS
Crane, IN	6.6	7.9	NA
DDBC	NA	6.0	NA
DDCO	NA	3.6	NA
DDCT	NA	4.0	NA
DDDC	5.7	6.9	19.7
DDHU	NA	4.0	NA
DDJC	5.9	7.1	NA
DDJF	4.9	5.9	16.8
DDNV	9.7	11.6	33.3
DDPH	4.2	5.0	NA
DDPW	8.1	9.7	27.9
DDRV	7.8	9.3	NA
DDSI	6.8	8.2	NA
DDSP	9.6	11.5	33.1
DDWG	NA	5.0	NA
DDYJ	7.8	9.4	NA
TRF Bangor	9.7	11.6	33.2
TRF Kings Bay	NA	4.6	NA
USS EMORY S LAND	NA	13.0	NA
USS FRANK CABLE	2.0	NA	NA

Table T.2. Predicted Shipping Time Values (YOKOSUKA)

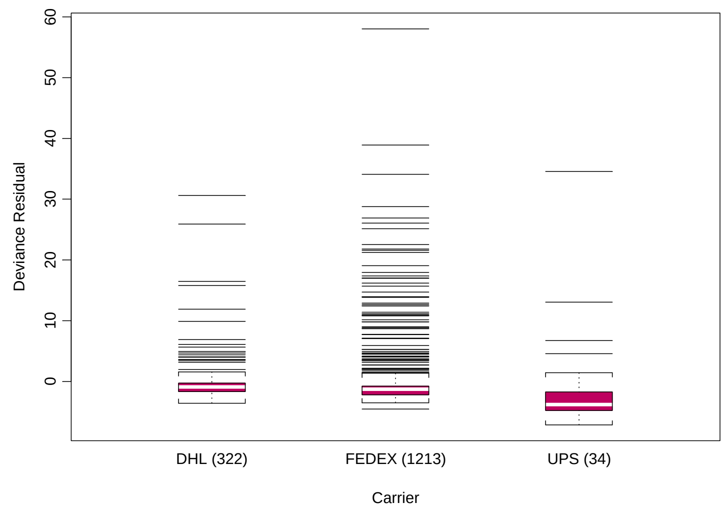


Figure T.3. Boxplot of Carrier Residual Deviances (YOKOSUKA)

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Chambers, J.M and Hastie, T.J., *Statistical Models in S*, Wadsworth & Brooks/Cole Advanced Brooks & Software, 1992.

Conover, W.J., *Practical Nonparametric Statistics*, 3d ed., John Wiley and Sons, Inc., 1999.

Conversation between Commander Jonathan Haynes, Commanding Officer, Priority Material Office and the author, 21 February 2008.

Defense Logistics Agency, *Customer Assistance Handbook*, 16th ed, 2007. (04.17.2008)

Defense Logistics Agency, *Strategic Plan FY07 – FY13*, 2007. (04.17.2008).

Denham, Kenneth R., *Human Factors Analysis of Fiscal Year 90 to 97 Rotary Wing and Tacair Flight Mishaps*, Master's thesis, Naval Postgraduate School, Monterey, California, June 2000.

Department of Defense, *FY2000 Department of Defense Logistics Strategic Plan*, 1999. (04.17.2008).

Hamilton, L.C., *Regression with Graphics*, Duxbury Press, 1992.

Haynes, J., *PMO 101*, April 2008.

Haynes, J. <jonathan.haynes@navy.mil>. [E-mail to Gavan Sagara <gsagara@nps.navy.mil>] 24 April 2008.

Hesterberg, T. C., Moore, D. S., Monaghan, S., Clipson, A., and Epstein, R., *Introduction to the Practice of Statistics*, 5th ed., *Chapter 14: Bootstrap Methods and Permutation Tests*, [http://bcs.whfreeman.com/ips5e/content/cat_080/pdf/moore14.pdf], 2005. (06.07.2008).

Insightful Corporation, *S-Plus® 8 for Windows® User's Guide*, May 2007.

The Mathworks, "Statistics Toolbox," [http://www.mathworks.com/access/helpdesk/help/toolbox/stats/index.html?/access/helpdesk/help/toolbox/stats/friedman.html], 2008. (05.20.2008).

McCullagh, P. and Nelder, J.A., *Generalized Linear Models*, 2d ed., Chapman and Hall, 1989.

Naval Supply Systems Command, *Naval Supply Procedures*, *Afloat*, *Volume I,* NAVSUP P-485, October 1997.

Naval Supply Systems Command, *Real Time Reutilization Asset Management System (RRAM), for FSPC/ESPC,* May 2006. (04.17.2008).

Priority Material Office, "Command History". (03.03.2008).

Priority Material Office, *Priority Material Office Code 20 Standard Operating Procedures,* January 2008.

Priority Material Office, "ISIS," [PMO, [https://www.pmohq.navy.mil/ISIS.aspx], 2008. (05.20.2008).

Schorn, Brian, *Multivariate Analysis of the Effect of Source of Supply and Carrier on Shipping Times for Issue Priority Group One (IPG-1) Requisitions,* Master's thesis, Naval Postgraduate School, Monterey, California, September 2003.

Snow, G.L., Chihara, L.M., and Hesterberg, T., *S-PLUS® Guide for Moore and McCabe's Introduction to the Practice of Statistics*, 5^{th} ed., W. H. Freeman and Company, 2005.

Vickers, C.M., *A Comparison of Commercial Express and the Defense Transportation System in the Movement of Reparable Assets Within Western PACAF*, Master's Thesis, Air Force Institute of Technology, Dayton, Ohio, September 1997.

Wikipedia, "Resampling (statistics)," [http://en.wikipedia.org/wiki/Resampling_(statistics)], 2008. (05.20.2008).

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Commanding Officer
   Priority Material Office
   Bremerton, Washington